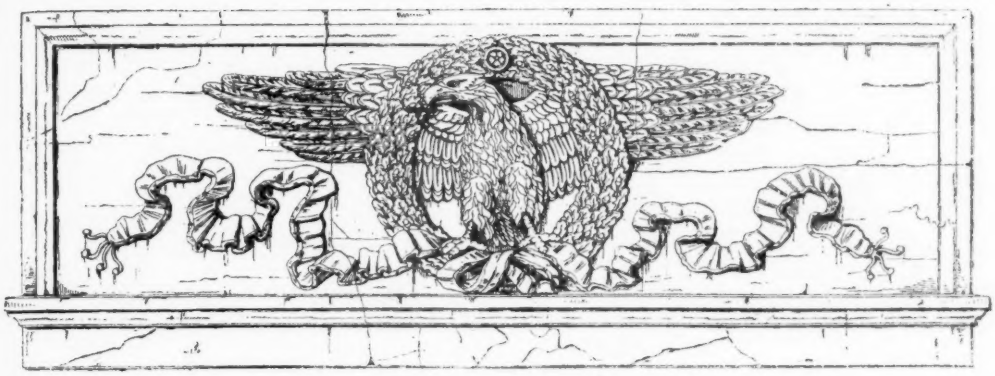


ON THE PLANNING OF COLLEGIATE BUILDINGS.

By the Rev. J. B. Lock, M.A.

FELLOW AND BURSAR OF GONVILLE AND CAIUS COLLEGE, CAMBRIDGE.

Read before the Royal Institute of British Architects, Monday, 16th May 1904.

IT is a bold action on my part to presume to speak on an architectural subject before this the leading Society of British Architects, even when I am fortified by the request of your President, and I must premise that I have neither the training nor experience to entitle me to speak with authority, which I do not pretend to do.

The colleges which have come down to us from the fourteenth and fifteenth centuries were all built on much the same plan. A court or quadrangle was enclosed by buildings which contained a chapel, a hall, a library, kitchens, buttery, lodgings for the master or head, rooms for the fellows and their pupils, and an entrance gateway with a porter's lodge. The chapel was of course on the north or on the south side of the quadrangle, and the court was accordingly placed as nearly as possible east and west, and was generally approximately a square. The buildings enclosing the college court were nowhere more than one room in width. Thus the chapel, the hall, the library, all had windows on two of their opposite sides, and this is true also of the principal parts of the kitchen, &c., and of most of the rooms for the master and fellows.

The advantages of the grouping of the various parts of a college round an enclosed court are obvious, providing as it does for security against thieves and undesirable strangers from without, for quiet retirement and seclusion within. Of late years, however, the additions to colleges have rarely taken the form of a completely enclosed court, and it is interesting to consider the reasons for this change in plan. The courts of colleges built in Cambridge before the sixteenth century were all small; they were all more or less rectangular, and their dimensions vary from 70 feet to 150 feet. The buildings enclosing these ancient courts were never more than two floors in height; probably one of the reasons for this was that in no college were there more than a very few fellows, so that there was no need for more rooms than were provided by the arrangement. Whether this was so or not, and whether the same reason was the cause of the limitation in the width of the buildings to one room only, it is certain that these two points, lowness and narrowness, are important points in the question as to the desirability of the plan of an enclosed court.

To the lowness of the buildings is, I believe, in great measure due the beauty and feeling

of rest that seems to pervade these old courts. It is certainly true that there is something oppressive in a small court surrounded by high buildings.

And in a large court it would seem that lowness of the enclosing buildings is in itself a cause of beauty. Let any one stand in the Great Court of Trinity College, Cambridge; he at once feels what a beautiful court it is. And if he considers to what this beauty is due, he will see that it is not to any continuous decoration of the component parts; he will, I think, admit that it is due partly to the great size of the court (it measures about 300 feet by 275 feet), partly to the irregularity of the buildings, but chiefly to the quiet simplicity of the low ranges of college rooms which make up two of its sides, and which modestly permit the greater heights of the gates, of the chapel, and of the hall to assert themselves. In one corner is the modern building containing the Combination Room of three floors with large sash windows; the effect of this building is fortunately lost in the vastness of the surroundings; but let the spectator try to imagine the two ancient sides of the court to be replaced by these so-called improved Georgian buildings, and he will realise how much our ancient courts owe to the fact that their builders were content with a very simple façade and a height of two floors only. The recent example of Keble College, Oxford, illustrates this point. There a court of ample size is enclosed by lofty buildings of three floors, whose height is intensified by the level of the ground in the centre of the court being somewhat lower than at the sides. It will be obvious to an observer how much more beautiful the effect of the whole court would have been if the ranges of rooms could have been kept down to a height of two floors only, so as to allow the lofty heights of the chapel, the hall, and the entrance gateway to have broken up the line of the enclosing buildings.

But there is still another reason for keeping down the height of buildings, at any rate on the south side of a court; in that the higher the building the more sunlight is cut off by it from the interior of the court. It may be for this reason that we generally find the chapel placed on the north side, as being of greater elevation than buildings containing sets of rooms. It is worthy of notice that when Dr. Caius enlarged Gonville Hall by building what is now called Caius Court in our college, he bounded his court on the south side by a wall broken only by the insertion therein of his beautiful Gate of Honour. Not only so, but, in the thirtieth of the new statutes which he gave to the college, he has expressly forbidden the erection of any building which shall completely enclose this court on the south side, "lest the air from being confined within a narrow space should become foul and so do harm to us and still more to Gonville's College."

In contrast to the anxiety of Dr. Caius lest the free admission of sunlight and air into his court should at any time be interfered with, is the action of the trustees of the will of Dr. Whewell, late Master of Trinity, who died about forty years ago. The courts called Whewell Courts, forming an addition to Trinity College, are two small courts, measuring one about 50 feet by 40 feet and the other about 110 feet by 70 feet; they contain only sets of living rooms, and are enclosed on all sides by buildings of three and four floors. It seems strange that those responsible for the erection of these courts should have thought the free circulation of air and the admission of direct sunlight into rooms of so little importance. Quite recently an attempt has been made by greatly enlarging the windows to improve the appearance and lighten the gloominess of these rooms, with no doubt a certain amount of success.

With regard to the planning of the arrangement of hall, chapel, master's lodge, kitchens, &c., it does not seem possible to say much generally, as so much depends on the circumstance of the site and on the requirements of a college.

It may be noticed that the arrangement by which the buildings were in general only one room deep caused the kitchens, &c., to be placed at one end of the hall; an arrangement

which has the advantage of keeping the odours of the cooking to some extent out of the hall. At the kitchen end of the hall it was customary to have a passage going right through the building and cut off from the hall by a screen with a gallery above. In modern times the passage has in many cases become a thoroughfare leading from the old court to newer courts beyond, with the consequent disadvantage that all the kitchen service now passes across the busy thoroughfare. The plan, adopted in several instances in the last century, of building the hall over the kitchen has an obvious advantage in economy of space, but it greatly favours the admission of the air from the kitchen into the hall, a drawback which certainly did not seem serious to Salvin, the architect of the new hall at Caius; for until about ten years ago the windows (which are on both sides of the hall) were arranged to open on one side of the hall only. The advent of the electric fan, however, enables us to a great extent to put an end to this difficulty.

The position of the hall recently built at Girton College is obviously convenient. It is placed at some distance from the students' rooms, and is approached by the students from two directions, through an enclosed passage or cloister opening into the hall on its south side, while the kitchens are placed in a separate building on the north side of the hall. It might perhaps be excusable to remark that the hall of Caius College, being above the kitchen, was provided with an oak boarded floor, instead of the stone or marble floor usual in a ground-floor building; and that this has been found useful (in a way which I fancy was not foreseen by the builders thereof): it makes a capital floor for dancing on the occasion of the annual college ball in the May Term, and is much patronised by Fellows' wives for children's dances.

Now I turn to the arrangement of the ranges of sets of rooms for Master, fellows, and students. In the olden time the Master simply had his one or two rooms in which he lived, a bachelor; as were all inmates of colleges in those days. These rooms were generally between the hall (at the further end of it from the kitchen) and the library. But in modern times the Master of a college requires a good house with all the offices and belongings of a modern residence. So that the lodges of our day are either curious and interesting conglomerations of buildings gradually annexed or added by successive masters, or are brand-new modern mansions built on detached sites in recent times; to criticise them would be to criticise a series of houses built at various periods in the last three centuries.

We come, therefore, to the fellows' and students' rooms.

In the ancient buildings the accommodation provided for each fellow consisted, in general, of one large room. This room was enclosed by its sport-door which opened on to a staircase or passage, and in nearly all cases the depth of the room was the same as that of the building. Thus the rooms were lighted by windows on two opposite sides; the walls were generally panelled with wood; the floor was more or less roughly laid with oak slabs, and there was a large fireplace with a wide and open chimney, and an overhanging mantel above a flat hearthstone. In this one room a fellow or tutor would live with his two or three pupils. There might be in the recess between the chimney and the outer walls, a small study in which the tutor worked by day, but at night the tutor and his pupils all slept in the large room. It should be noticed that these rooms were in some ways admirably adapted for a healthy abode for several inmates. The windows on opposite sides of the room provided means for a through current of air at any time. The fact that two opposite walls were *outside* walls ensured that sunlight should in every case be admitted at some time in the day, no matter what the aspect of the room. In the floors and walls were plenty of chinks and cracks through which air could get into and out of the room; while the chimney was in section many times greater than the modern chimney, measuring, as it often does, only 9 inches by 9 inches. Any one who has lived as I have throughout the year in such a room knows that while it is

not easy to keep it warm when a cold wind is blowing outside, yet it is never stuffy, unless it is crowded by a large number of men.

Thus it will be seen that the plan of the sets of chambers or men's rooms in the ancient building was a very simple matter. The building was merely sliced up by the insertion of stacks of chimneys and wooden partitions, with staircases of one flight at the proper intervals. In colleges at the present day ranges of buildings containing living rooms have to be divided up into sets; each set containing at least one sitting-room, a bedroom, and a pantry, or gyp's room. And when we remember that a very large number of these sets of rooms are required to be as economically and as conveniently arranged as possible, it will be seen that the problem of building additional college rooms is in these days somewhat more complex than formerly.

There are a few points which should be borne in mind with respect to a *set of rooms*. It is usual that each set should be enclosed by a stout door called the oak or sport-door, and it must be remembered that the set is practically a small house or "flat" (without kitchen and other offices), which is the home of its tenant, and ought to be suitable for habitation in health and in sickness. Therefore the following points should, if possible, be observed in all cases. (1) The sitting-room should have some sunlight; (2) the bedroom should have not less than 100 square feet of floor space; it should have plenty of window space that can be opened, and a place for the bed out of the draught; it should have a chimney and other means of ventilation; (3) There should be a possibility of providing for the passage of a current of fresh air through the rooms when the sport-door is closed; and for this purpose the windows of the sitting-room and bedroom should not all face the same way.

This last requirement seems to be of very great importance, and it is one which is apt to be overlooked. As has been said, a set of rooms should be regarded as a separate house; it therefore ought to satisfy all the reasonable requirements of a house. In all building bye-laws of recent times great stress is laid upon the provision of air space both in the front and in the back of a domestic building; and for a very good reason. In order to change the air in a room quickly and effectually it is necessary that a through current of air should be set up in it. Of course if a fire is burning in a room, the chimney is a mechanical means of ventilation, and acts as a suction pump, taking out of a room a considerable quantity of air per minute, and consequently causing an equal quantity of different air to enter. This air enters from the windows, the door, the cracks in the floor boards, and through the walls; and if the air coming in is fresh the fire will mechanically keep the room well ventilated. It might be worth while to note here that we have the authority of Dr. Shaw, F.R.S., Director of the Meteorological Office, for the statement that a fire in an ordinary grate is a mechanical means of ventilation sufficient, roughly speaking, for *four* persons. But as in this country we do not keep fires burning all the year round, and we do not as yet, in ordinary circumstances, provide any other mechanical means of ventilation, the possibility of ventilating a house simply by the movement of the outside air becomes of vital importance. If we have a window open in a room and there is no other opening in the room, such as a chimney or an open door, the wind, even if blowing outside directly at that window, will cause very little air to enter that room. A certain amount of disturbance will be set up in the air in the room (of the nature of a vortex motion) in the immediate neighbourhood of the window, but very little *change* will take place in the air in the room. That is to say a single open window, and no other opening, is not an efficient means of ventilation. If there is a chimney in the room with an up or a down draught it will improve matters considerably; but to ventilate by one open window only is like trying to get circulation, in a room crowded with guests at an "at home," through one solitary door. There is no circulation, only disturbance.

It seems, then, to be of great importance that every set of rooms should be provided with

adequate means for summer ventilation by arranging that the windows of sitting-room and bedroom should not *all look the same way*; for it is then possible by opening windows looking to different points of the compass to set up a through draught.

I proceed now to consider how the points which I have laid down as desirable in a set of rooms can best be obtained, regard being had to economy of space and the convenience of service.

Economy of space in nearly all cases demands that we shall have buildings of three floors and an attic, and the colleges nearly always ask that at least eight sets of rooms shall be provided on each staircase. One reason for this (besides economy of space) is that for convenience of service it is an advantage to have them so arranged, because a scout or bedmaker can attend to at least eight sets.

The question therefore arises, why not put four sets of rooms on each floor approached by one staircase? This would give, with two floors and an attic, either ten or twelve rooms to each staircase, and would economise frontage space. This arrangement, if a plan could be devised free from objections, would have many obvious advantages. It would seem, however, that this is not very easy.

I know of only one instance in Oxford or Cambridge in which the arrangement of four sets of rooms on a floor has been adopted. I give a rough diagram of the plan. In it A_1, A_2, A_3, A_4 are the sitting-rooms; B_1, B_2, B_3, B_4 the bedrooms; D is the scout's hole or gyp-room. The plan is open to the following objections: (1) It will be seen that when the sport-doors leading to the lobby, E, are shut, there is no possibility of a through ventilation of any one of the four sets of rooms, except through one of the others; (2) C_1, C_2, C_3, C_4 are passages which are without direct light or ventilation; (3) the lobby, E, is badly lighted and badly ventilated. The particular building in question faces east and west, so that both the sitting-room and bedroom in each set gets some sun; it is obvious that if the buildings faced north and south, the north sets would have practically no sunlight in either room.

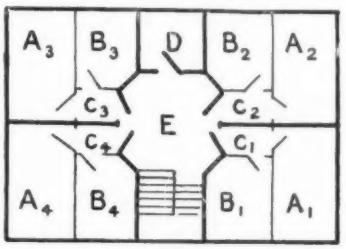


FIG. 1.

Of these objections none are, I think, fatally serious except the first. No house, probably no flat (but I am not familiar with the byelaws concerning flats), would now be allowed by any byelaws to be built back to back with another house, and therefore I think that no set of college rooms should be allowed to be so built. So far as I know, no other solution of this problem has been suggested, and it may therefore be said to be best to have only two sets of rooms on a floor on each staircase. It follows from this that, in general, the sitting-room and bedroom windows will look in opposite directions and our building will have a front and a back, if we agree and call the *front* the elevation in which are the sitting-room windows. (It will be remembered that in ancient college buildings the living rooms had windows on two opposite sides, so that in those days there was no front and no back to the buildings.)

Can we now give any answer to the question, What is the best typical arrangement of sets of college rooms? A great deal must, of course, depend on the site available, and a great deal on the aspect of that site. If we accept the rule that sitting-rooms must look into the "court," or what takes the place of a court, and are agreed that a sitting-room should have sunlight at some time in the day, it will follow that a range of college rooms must not be placed on the south side of a "court."

This result, although here arrived at for quite different reasons, fortunately agrees with the statute of Dr. Caius, viz. that a "court" should be open on the south.

After a careful comparison of plans which have been adopted in recent times at both Oxford and Cambridge, it seems to me that the plan recently adopted, quite independently, by Mr. Champneys at New College, Oxford, and by Messrs. Aston Webb and Ingress Bell at Gonville and Caius College, Cambridge, is one of the best.

The arrangement is here shown in figs. 2 and 3, giving a portion of the plans of St. Michael's court. This building faces south-west towards a narrow court. The staircase is on the north-east, and is approached from the court through a passage about four feet wide. On the ground floor on each side of this passage is a set of rooms, of which the keeping rooms face south-west, the bedrooms north-east; the gyp-rooms also face north-east (a good aspect for a pantry). Again, when the sport-doors are shut, the opening of a window in sitting-room and bedroom, one on each side of the building, gives excellent ventilation; so that these rooms satisfy the hygienic conditions already laid down. The staircase is thoroughly well ventilated; with a window open on the staircase, air can blow right through the building from the entrance passage to this window. On the first floor, as the space over the entrance passage is available, we have the whole frontage to the south at our disposal for division between the two sitting-rooms. In the plan adopted at Caius College the space over this passage is all thrown into one room, making the rooms on each side of unequal size; at New College, Oxford, this space is divided equally between the two sitting-rooms.

In fig. No. 4 is shown the arrangement adopted in the Tree Court at Caius College in the new buildings by Mr. Waterhouse, R.A., in 1870. Fig. 5 shows the same space arranged in accordance with Messrs. Aston Webb and Bell's plan in order that a comparison of the two may show their respective advantages. One objection to No. 4 is that the gyp-room opens directly on to the staircase landing and is not included within the sport-door. This was done in 1870 after careful consideration, and for the reason that it was originally proposed to provide in each gyp-room a *sink* and waste for the use of the bedmaker. If this had been done it would have been obviously undesirable to put the gyp-room *within* the set of rooms, as there would then have been a direct communication with the drains close to the bedroom. It was subsequently decided not to provide a waste in the gyp-rooms, and by a slight alteration these rooms could have been included within the sport-door, an alteration which will probably some day be made. A more important objection is that the staircase has no independent *through* ventilation. This, again, is not a very vital objection. But the great advantage of Plan No. 5 over Plan No. 4 is that the first gives the whole of the front above the ground floor to the sitting-rooms, thus giving an opportunity of opening additional windows, and therefore providing additional sunlight and air for those rooms.

The rule that a court set aside for sets of rooms only should have no buildings on its south side has been very generally observed in recent additions to colleges in Oxford and Cambridge, so that these additions have usually taken the form of a straight line, or of an L, or of a U. Now, assuming that it is wished that no sitting-room should face north, it is clear that a difficulty arises in the *angles* of the U and of the L; and this brings me to another point on which I should like to say something.

It will be obvious to those examining the new buildings in Oxford and Cambridge that when the general plan of a building has been settled, it has been the custom in planning out the allotted space into sets of rooms to practically choose a certain arrangement and then *repeat* that arrangement on each staircase. It happened in the recent work at Caius College that a certain irregular site, covered by a row of houses of different sizes, had to be replaced (after pulling down the houses) by a college building containing sets of rooms, and it was

essential that practically the same cubic space should be occupied by the rooms as was then occupied by the houses. The irregularity of the site was such that uniformity of plan could only be attained by sacrifice of space. The college had therefore to determine how far irregularity of plan was objectionable. They had had experience of uniformity of plan in the

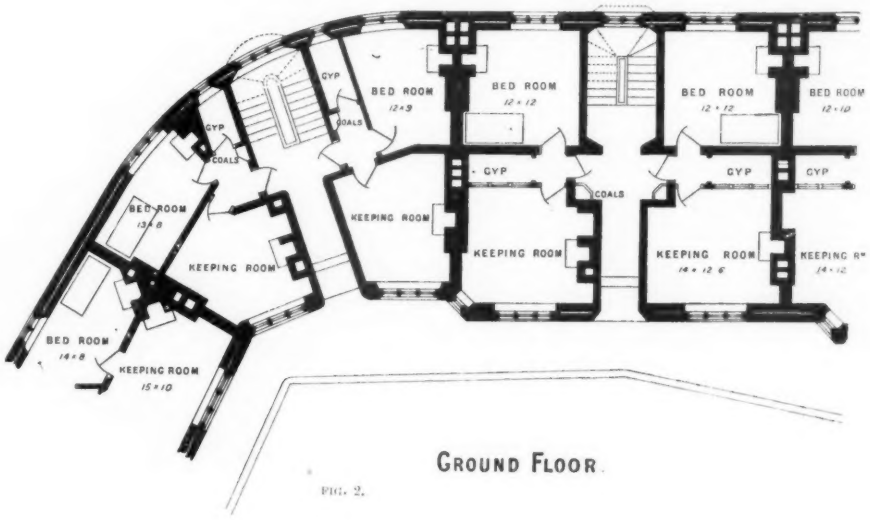


FIG. 2.

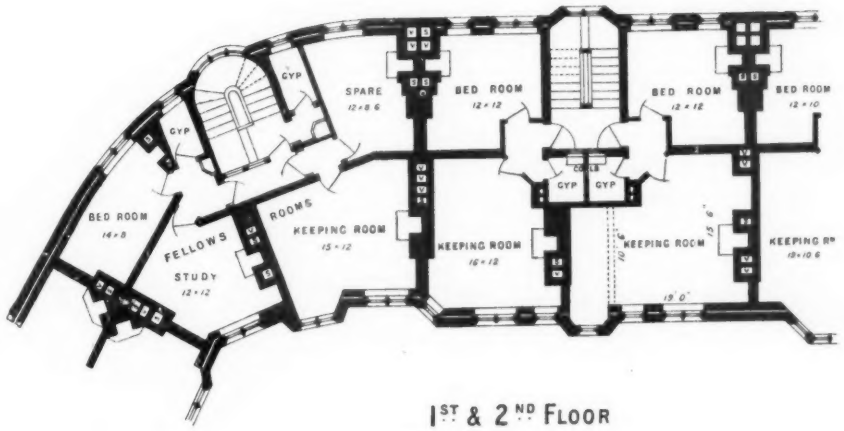


FIG. 3.

ST. MICHAEL'S COURT, GONVILLE AND CAIUS COLLEGE, CAMBRIDGE.

Waterhouse building in 1870, and after careful consideration they decided that in their opinion irregularity of plan was desirable rather than otherwise, and the architects were instructed to give as much variety in the size and shape (within certain limits) of the rooms as they conveniently could. Probably in this we are only following the fashion of the day; for in the plans which one sees nowadays of many country houses and town mansions, one cannot

help being struck by the irregularity of the plans, and by the variety of the size and shape of the rooms. The result in our new court at Caius is that hardly two sets of rooms, out of fifty, are exactly alike.

The irregular site of St. Michael's Court is practically an L with an angle at the corner of about 120°. And it is the solution adopted by our architects of the problem of how to deal with the corner that seems to me instructive. The plan which I have advocated for a straight building is still kept, but the rooms, particularly the sitting-rooms, take a very unusual shape. The arrangement is shown in figs. 2 and 3.

Here, then, seems a solution of the difficulty of how to deal with a corner of an L or a U which, provided you do not exact the condition that all rooms shall be rectangular, avoids many objections. In order to illustrate the advantages of the arrangement, I have adapted it to the first floor of the building in the corner of the Tree Court of Caius College, in order that we may compare it with the existing arrangement. The two arrangements are shown in figs. 4 and 5. The new plan [fig. 5] gives two sets of rooms, with sitting-rooms, each facing S.W., of very irregular shapes. The shape, however, seems to me to be not uncomfortable. It provides an ample staircase well ventilated, with good space for bedroom and gyp-room. The existing plan [fig. 4] provides two sets of rooms which in size and shape are excellent, but one set has all its windows looking north. And as the building looks on to a narrow lane with high buildings on the opposite side, the rooms, notwithstanding their good size and shape, are not popular. The corresponding rooms on the ground floor are practically unsuitable for habitation, and are used as offices. The other set of rooms has windows all of which look in only one direction—viz. east; and they therefore transgress the rule laid down above. Fortunately, the street on this side is wider, and there is an opening in the opposite side of the street, so that these rooms do get a certain amount of sunlight.

In comparing these two plans it must be remembered that with a clear site a considerable amount of modification could be introduced in the proposed corner arrangement; but from our experience with the irregular rooms in St. Michael's Court, it would seem that mere irregularity of shape is no detriment to a college room. The important points are: Is it comfortable? Has it sunlight? Is it airy?

The points which I have ventured to attempt to emphasise in the planning of college rooms are in the main three: (1) the desirability of having some sunlight in the sitting-room in all cases; (2) the importance of it being possible to set up a through current of air through every set of rooms independently of the staircase; (3) the desirability of having a through current of air through the staircase itself. And I have given a plan of sets of rooms which provide all these advantages in rooms facing south or east or west.

It is also suggested that the plan of an enclosed court is not suitable when the enclosing buildings are lofty, and if a court must be enclosed on the south, it would serve best that the hall or chapel or master's lodge, or any building other than one occupied by sets of rooms, should occupy the south side.

The point which is here raised, as to the desirability of having windows in living rooms on more than one side, applies with equal or greater force to all rooms intended to be used as chapels, halls, lecture-rooms, laboratories, or class-rooms. It would seem that unless such rooms are provided with an efficient system of mechanical ventilation in summer as well as in winter they should never be built without windows, or at least openings to the outer air on two *opposite* walls.

Finally, I would venture to plead with Architects not to grudge a large share of attention to the use to which a proposed building is to be put. While the Universities of Oxford and Cambridge owe a great debt to great Architects of the past century and of the present day,

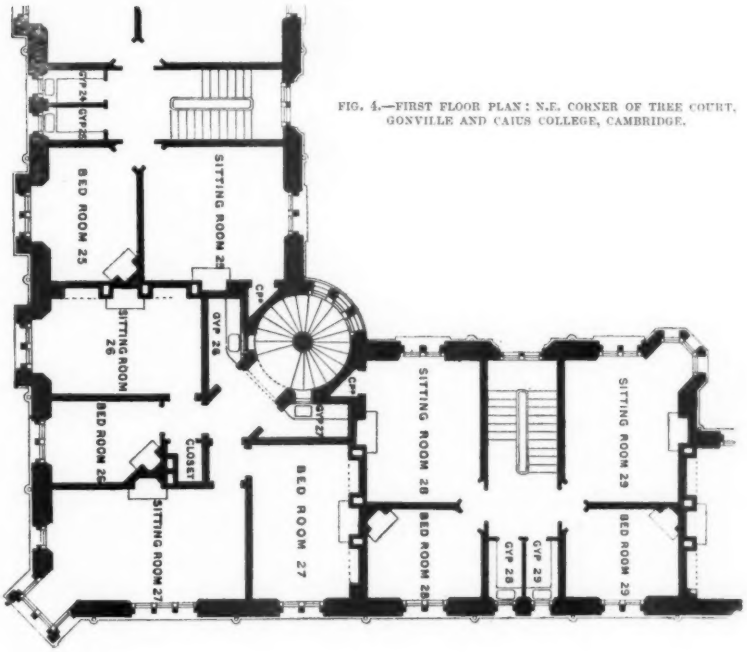


FIG. 4.—FIRST FLOOR PLAN: N.E. CORNER OF TREE COURT, GONVILLE AND CAIUS COLLEGE, CAMBRIDGE.

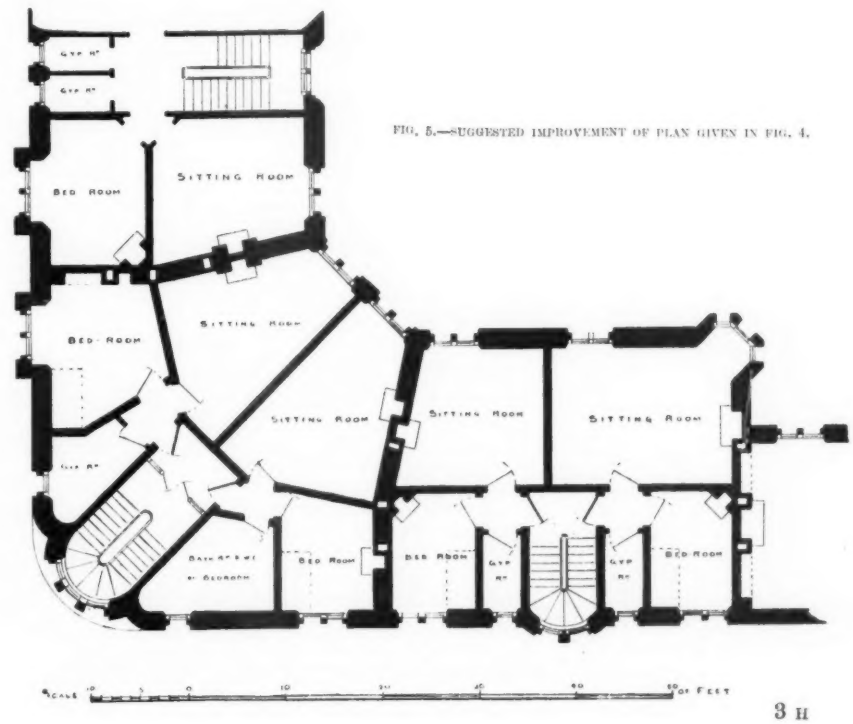


FIG. 5.—SUGGESTED IMPROVEMENT OF PLAN GIVEN IN FIG. 4.

yet we have to lament many mistakes. Whether these mistakes were due in any particular case to the Architect, or to the committee entrusted with the duty of instructing the Architect, it is often not possible to say. But when we find an addition to a library with a very artistic and effective elevation, in which the windows are far too small for their purpose, and the ground-floor rooms are actually unfit for use on account of their dampness; when we see college rooms, with the sitting-rooms looking north, on a dusty and noisy street, instead of south, into a quiet and sunny court, presumably because the elevation towards the street suited that arrangement; when we have an ornamental building put up for the use of University Press, with windows so small that the building is practically useless; when we hear of a series of lecture rooms of costly and elaborate design so wanting in effective means of ventilation that they are described by those condemned to use them as *pestilential*; I think we may fairly appeal to Architects to first consider carefully the use to which a building is to be put before they design their façade. I fancy I remember seeing a report of a speech by your President in which he advised Architects not to put *all* they knew into a façade; I would ask them to spare *a large share* of their genius and experience for the planning of the building. Surely the chief beauty of a building is that which arises out of its perfect adaptation to the uses for which it is designed; and often difficulties of site or arrangement suggest variety in treatment of the exterior which, springing as it does from the requirements of the plan, is a source of pleasure to all who are familiar with the convenience provided.

"A thing of beauty is a joy for ever." But how can a building which is unsuitable for its purpose be a source of joy to those who have to use it? How can a college building which is not healthy and pleasant to live in be a source of satisfaction to the members of the college, even if the façade is in itself greatly admired? Is it not possible that the taste of the next generation may condemn that very façade? and where then will be the beauty of the building? Whereas a building eminently suited for its purpose must *ipso facto* be superior to the influences of time and taste; it has in itself the essence of beauty; it is a source of satisfaction to all who use it. A building, to be a thing of real beauty, must be a joy, not only to the passer-by, but to those whose lives are spent within its walls.

DISCUSSION.

The President, Mr. Aston Webb, R.A., F.S.A., in the Chair.

Mr. BASIL CHAMPNEYS, who rose at the invitation of the President, said it was but a short time since he had delivered himself on the same subject in that room.* He would, however, make a few remarks that had occurred to him during the reading of Mr. Lock's very excellent and practical Paper. Of course the author had dwelt more upon the practical than upon the historical. The whole system of college rooms was absolutely transformed in the sixteenth and seventeenth centuries. The old plan was that there should be one large room where a Master of Arts and students slept together, and adjoining this, generally opening out of it, were two small studies. Many of these survive in the old buildings at New College. When that was the case a very small college would accommodate a great many students, and supposing that one of these sets took one master and possibly half-a-dozen students, there would be, for the same building, accommodation for six times as many as when the time came for each student to have a separate pair of rooms. The adaptation usually was that the large room was taken to be the undergraduate's sitting-room, one of the small studies was taken to be his bedroom, and the other served for the gyp-room. There were numbers of college buildings surviving in Oxford in

* "The Planning of Collegiate Buildings," by Basil Champneys, B.A.; Journal R.I.B.A., Third Series, Vol. X., p. 205.

which the old partitions remain exactly as they were at the time they were built in the fourteenth or fifteenth century; it was simply the uses of the rooms that had been altered. That, of course, affected both the question of height and of size. In the old days, when the accommodation was put to so much larger purposes, they did not want to build upwards, and two floors were probably enough. In the later buildings for the most part were two floors and an attic. If the promoters of the present day—as he understood Mr. Lock to say—required three floors and an attic he very much regretted it. He had rarely seen three floors and an attic which had not looked to him altogether too high for collegiate purposes. He had so far been fortunate in persuading his clients never to go beyond the two floors and an attic, and he hoped in the future he might be equally successful. He had dwelt on that point in his last Paper, and mentioned two or three buildings which did not satisfy him from the æsthetic side; and of course there was this practical side, that college servants felt the wear and tear of the stairs very considerably. Only the other day, the Bursar of one of the colleges for whom he prepared certain plans, impressed upon him the necessity of making the stairs not only easy in themselves, but taking off the wear and tear by putting down lead or something of that kind, because the servants were constantly complaining of the staircase. With regard to the size of quadrangles, he heartily agreed with Mr. Lock that if they could possibly leave the south side open, closed by a railing, or what not, it was an enormous advantage to the whole building. They could not always secure that the sitting-rooms in a college should have a south aspect, but wherever it was possible it ought to be done. He thoroughly agreed with the idea of through ventilation where it could be obtained, and this involved the moot point whether there should be a door from the sitting-room to the bedroom; and, of course, settled the point in favour of the door. With regard to the Masters' Court at Trinity College, Cambridge, he felt with Mr. Lock that the size of the quadrangle was absolutely insufficient. He was one of the first occupants of a set of these rooms when they were built, but fortunately he happened on rooms which looked out into All Saints' Passage, and so got plenty of light and air; but some of his friends, who looked into the quadrangle, had since met with various unhappy fates. Whether it was due to the smallness of the quadrangle or not he could not say. However, he had an airy and well-lit room and had survived. Some very curious and interesting things had come to light about the kind of way in which college rooms were used by the masters of the colleges. He had lately had an instance of a warden of the last century who used, whenever the Fellows went down for the Long Vacation, to burrow into their rooms, and when they came back they found no rooms to receive them: they had been absorbed into the master's lodge. Nearly a whole side of the quadrangle had been so incorporated, and the poor Fellows were left to whistle for their accommodation. A question of considerable importance, which Mr. Lock had only touched upon indirectly, was whether fireplaces should be considered to be a necessity in bedrooms. He, personally, had no great belief in the ventilating power of fireplaces when there were no fires in them. They were as apt to work downwards as upwards, and when they worked downwards they introduced a sooty sort of atmosphere into the room, which was apt to do rather more harm than good. In his experience the fireplaces in the college bedrooms had very rarely been used. Nowadays they were not so dependent on windows as they used to be; they had various means of obtaining ventilation which were not known to their ancestors; Tobin ventilators had great advantages, and were exceedingly useful things to introduce into rooms. There was a rather larger question he wanted to mention as a possible new departure. In the first place, as to gyp-rooms, as they called them at Cambridge, or scouts' holes, as they were called at Oxford: it had been the tendency lately at Oxford to make one fair-sized room answer for a whole staircase. It had been found very useful to have a somewhat large gyp-room or scout's hole containing a gas, or some other, stove, so that they could get hot water at any time without having to oppress themselves with a fire. As to coal-stores, if they were planning rather close, and had not many spare spaces, it was a little difficult to get stowage for each undergraduate's coal. Of course, there were various ways of meeting that—each man could have his little coal store in the basement, and the servant could bring it up; but that meant a good deal of labour, and it would be better to get the man who brought in the coal to put it where it would be handy. Speaking in the presence of a Bursar, he spoke with great diffidence; but it might probably be that in many colleges there would be a regular rate chargeable for coals, that there would be a common store, and that it would not be necessary to assign to every man his exact little quantity of coals. On the whole he was inclined to think that the individual coal-bins, or at any rate the individual supply of coals to each undergraduate, might be simplified. Baths he found were more and more needed. It would, he thought, be easy to supply, for a set of college rooms with so many staircases together, a number of baths which might be used by roster, or in some other way. They would be a most desirable adjunct. The principal point of all was the staircase arrangement. He had lately had to meet the problem of getting the largest possible number of rooms into a very limited space, and he found that he could get this far

better by making the staircase external to the main block, and of the spiral type. Looking at the plans on the walls it would be seen that, to use an American phrase, the staircase cut a big chunk out of the building. If it could be projected, the opportunity would be afforded of a picturesque feature, and, in addition, the general parallelogram of the building would be relieved of any diminution by the staircase He had not done this yet; he was going to do it for the first time, and perhaps a year or two hence he would be able to tell better how it worked out, and how it suited in actual use. He found that with a very limited space he was able to save on one side of an open quadrangle 11 feet and on the other side 22 feet by adopting this plan, and as the space was excessively valuable, it seemed that there were at least advantages in it. Whether where there was ample space and money this was the better method he was not prepared to say, but he did not see at present that there were any necessary disadvantages attending the plan. However, he spoke as a person about to embark on an experiment, and with the diffidence which was becoming to people in such a position.

MR. EDWARD S. PRIOR, M.A., expressed the extreme pleasure it had been to him to come to the meeting, and for many reasons. First, Mr. Lock was an old friend of his, and it was always a pleasure to hear him speak; secondly, it was always a pleasure to hear an expert speak upon a subject he knew thoroughly. Mr. Lock had been managing a college for some considerable number of years, and knew exactly what a college was, what a college needed, and what a college was used for. That led him to mention the third reason of his pleasure, which was probably that of all of them—viz. that they as architects had heard that evening a lay speaker, somebody outside their own particular view. It was not only healthy, but, with regard to architecture, it was very necessary for them every now and then to consider that there was another view outside their own as architects. He remembered at the Congress of Architects held some years ago the subject under discussion drifted into the function of architects, and a speaker eloquently, and at great length, put forward how the architect was the all and everything; he was the beginning and end of practically every function of modern life. He thought at the time that that was going a trifle beyond what was the case; in fact it seemed to him that after all the other side was perhaps rather truer, that the user was the all in all, and that the architect came in as a subsidiary to the user—that he, in fact, determined rather the way in which the thing was to be done than what was to be done; he contributed the imagination necessary to put the user's intelligence to the purpose for which it was intended. Mr. Lock had well rubbed that into them. As regards the history of the matter, he supposed the earliest collegiate buildings in the British Isles were the collection of hermits' cells, which consisted of a bell-shaped chamber with a seat on one side, in which the occupant passed his days sitting in the sun. From that collection of hermits' cells the building of colleges had gone on, step by step, until they came to their present position. The Middle Ages went a long way in the Chartreux. At Mount Grace considerable progress had been made towards a very excellent collegiate building. The fifteenth, sixteenth, seventeenth, and eighteenth centuries had all developed it, while now at the end of the nineteenth the collegiate building was shifting its ground and was really becoming a collection of flats. There were two or three tendencies in that direction which Mr. Lock had brought out; in the first place he had shown us quite truly that the enclosed court was no longer the best for a college building, but that one side of it should be open towards the south. Thus practically they were getting into the planning of flats. Another evolution Mr. Champneys had mentioned, that of the common gyp-room with a stove in it. This was a drifting away from the collegiate arrangement of old times; they were reaching a new era. What he wanted to observe was that if that were so, if the college was necessarily drifting into something else, why should they go back to any time, however picturesque, just to take the style of that time and call it "collegiate"? To do this was of necessity to make their new college buildings in forms which no longer fitted their requirements. In modern college buildings there was always this great difference from the old: the old had a certain space about it, there was a certain distance between its windows, and a certain breadth of wall; the new, having to meet new requirements, if it still aped those windows and tried to produce the effects of style, made a mess of it with different proportions and different sizes. The older collegiate styles were no longer of use in college buildings; the buildings should be erected in the forms that grew from the uses to which they were to be devoted.

THE SECRETARY (MR. W. J. LOCKE, B.A.Cantab.), referring to the common gyp-room, asked the author of the Paper how the bedmaker managed to separate the effects of the men on her landing or staircase. His rooms at Cambridge were arranged in this way: you entered from the oak into the sitting-room, which led into the bedroom, and that again into the gyp-room. His gyp-room he used as a bath-room, and he used the gyp-room of another man on the same landing which opened immediately on to his oak. Consequently their butter, cheese, eggs, beer, coals, and wood were all mixed inextricably; one never knew which was his and which was the other man's, and the bedmaker could not tell either.

THE REV. J. B. LOCK, replying to the Secretary, said that when they were planning St. Michael's Court, he went to Oxford for the purpose of going over the new buildings erected there in the last fifty years. In Mr. Bodley's beautiful building at Magdalen, he met a scout on the staircase taking from some rooms a tray of things down to his room below. He asked the scout if he would prefer to have a sink and wash-up place on each landing, or whether he preferred to take everything down to his own room? The scout replied that he much preferred to take them down to his own room. The result of this hint and of further enquiries was that in St. Michael's Court, which was a building of five floors, there was at the bottom of the staircase a little room in which there was a sink and a range, so that the bedmaker had a fire all the year round—a great advantage, they thought, for her health. In addition to this, in each set of rooms there was a gyp-room or small pantry which was intended as a storage place for the various provisions and beverages which the undergraduate liked to keep to himself. Mr. Champneys' remarks showed that he had thought a good deal about the minor details connected with the planning of college rooms. He spoke of the hard work it was for the bedmaker to go upstairs. The architects of St. Michael's Court suggested that they should have wooden treads to their stairs, as quiet and comfortable in use; the bedmakers thoroughly appreciated the advantage of not having to go up and down stone stairs. As they were going into details, he might mention that the bedmakers no longer had to carry their water up and down stairs; the water was provided by taps upstairs, and there was a waste on the staircase—he need not say, properly arranged. With regard to the doors between the bedrooms and sitting-rooms, from his point of view they were not necessary for ventilation because the two doors from sitting-room and bedroom into the lobby were so close together. Moreover, in order to secure a free circulation of air, they had in all cases put an opening with a hit-or-miss shutter over both these doors; the hit-or-miss was generally fixed open, which was the best way. Besides this they had in the bedrooms a separate ventilator, a ventilating flue carried to the top of the building, from which there was an opening into every bedroom near the ceiling. The fireplaces, which were seldom used, provided an opening near the floor; thus there was an opening at the floor and at the ceiling in every bedroom. The architects planned originally to have a hit-or-miss in those openings in the bedrooms, but he took the responsibility of leaving them out, as there seemed to be no circumstance under which they ought to be closed. That arrangement of ventilator and fireplace seemed to be good, because there circulation of air would easily be set up in a room with openings at the ceiling and at the floor. They had solved the problem of coals with great care. The architects had planned an extremely ingenious arrangement. There was an ornamental oak front in the staircase, and in it there was a ledge of the ordinary kind meant for parcels; the shelf of the ledge opened and disclosed a coal-box into which two hundredweight of coal could be put; a man had only to open the door of his gyp-room and he found his coals ready to hand. The problem was to find the least size of the coal-box in which the coals would always fall down to the floor without jamming; the clerk of works had had five different coal-boxes made before he hit on the right size. This arrangement avoided the necessity of the bed-maker carrying the coals upstairs, and had besides other advantages. The question of baths was a very pressing one. In St. Michael's Court they had arranged a place for them in the basement, and there was a committee just appointed to consider how they should be carried out. The solution, he thought, would be to have two or three shower-baths with dressing-rooms, as they had in the public schools.

MR. A. W. S. CROSS, M.A. Cantab. [*F.*], said he rose with considerable pleasure to propose a hearty vote of thanks to Mr. Lock for the very able and practical Paper he had been kind enough to give them. Most of them would remember Mr. Cecil Rhodes's description of college dons, a description based, presumably, on Mr. Rhodes's experience of the dons at his own University; but gentlemen in that room who had had dealings with the University authorities at Cambridge knew well that the characteristics to which Mr. Rhodes referred could not justly be applied to the large majority of members of the governing body of Cambridge University. In their visitor of the evening they were honoured by the presence not only of a scholar, and the author of a series of educational mathematical works which had materially assisted to lighten the burden of many an unfortunate undergraduate in his struggles with the inevitable and to him highly unnecessary examinations, which in many cases embittered his University career, but they had also the pleasure of meeting a gentleman to whom the members of his own college were under a great debt of gratitude for the very able and successful manner in which he had administered its finances for so many years past. In other words Mr. Lock, in addition to his varied accomplishments, was an excellent man of business. He had, too, shown them that evening that had he directed his attention to architecture he could scarcely have failed to attain high rank in one or more of its branches. He recently had the pleasure, under Mr. Lock's guidance, of inspecting the beautiful new buildings with which the President had enriched the ancient University and town of Cambridge, and the keen interest which Mr. Lock evinced in every

detail of the internal arrangements of the structure made one wish that the general public would take a similar keen interest in and show as great an appreciation of the architect's labour and thought.

MR. H. G. IBBERSON [*F.*], in seconding the vote of thanks, said that over the entrance gateway to the building in Rose Crescent, Cambridge, which had been referred to, there was some exceedingly beautiful carving, and in that carving were the figures of two little nude boys. He believed there was some discussion at Cambridge as to whom those little boys represented, and the final opinion was that they represented Dr. Gonville and Dr. Caius as "children in finance," a reference, of course, to the remarks by Mr. Rhodes *à propos* of University authorities in their business relations. He felt with the last speaker that they had a University professor with them that evening whose practical side had been shown, not only in finance as a college bursar, but also in building. But one had also a glimpse during his remarks of an artistic as well as a practical side, although repressed, and possibly not acknowledged: in dealing with those old courts there were certain references to the low reposefulness of the buildings which, although slight, were very feeling. That led him to make one reference to a suggestion that staircases should project into the court rather than be placed in the building. It occurred to him that such an arrangement would disturb the repose of the façade, and make the circulation of air in the court less satisfactory.

THE PRESIDENT said they had had a most instructive evening, and were very much indebted to Mr. Lock. Mr. T. G. Jackson, who had had so much experience of buildings of this class, had written to say that he should have liked to be present, but, as many of them knew, he had been ill; and though he was now better he was not yet able to come out at night. They all appeared to agree with Mr. Lock that the heights of buildings round courts should not exceed two stories and an attic. He could only regret that in the particular case with which Mr. Lock was concerned he fixed the height at three floors and an attic. That only showed the difficulty of carrying out in practice the principles one held in theory. With regard to another point of Mr. Lock's, the quadrangle surrounded on three sides and open on the south, he ventured to think that even that was not quite sufficient to secure the through draught which he very properly was anxious to secure. As he pointed out, if there was a window only at one end of the staircase, one would not get a through draught; and so, with a considerable quad open only on the south, one could not get a draught through it. In the Isle of Wight, in a very exposed position, he knew a sort of summer-house enclosed on three sides, in which one might sit facing the wind and not feel the wind at all. The space in which one sat was so full of air that the wind could not disturb it. There was, too, the well-known example of driving in a hansom cab where, if there is much wind, the doors would often fly open from the pressure exerted by the air in the cab. The only way to get cross-ventilation through the quad is to have the angles open also, and thus avoid the difficult angles which Mr. Lock had pointed out. A well-known example of that was the quad of St. Bartholomew's Hospital, Smithfield, which had remained for a great many years longer than it would have done if the angles had not been open, and so although the wards of St. Bartholomew's Hospital were side by side, and back to back, still the circulation through the quad had been secured by the open angles, and health had been maintained under it. As to the gyp-rooms, unfortunately neither Mr. Bell nor himself had the advantage of being University men, and they had to some extent to find these things out. They were rather surprised when they came to close quarters with it to find that, although there were gyp-rooms, the gyps had practically been given up—at any rate in Cambridge; he believed now they were called "bedders." For these bedders (there was one to a staircase apparently) one good room down below, with a little pantry attached to each floor, seemed to be the best arrangement at the present time. As to the aspect, every one would agree that a single room in which a young man had to live a good many hours a day ought to have some sun in it. Pembroke College, those very beautiful buildings by Sir Gilbert Scott, he happened to know very well. Its sitting-rooms faced a road and faced the north, and that was the only thing in those beautiful buildings one had to find fault with. On the staircase it seemed all bright and sunny, but entering the room one experienced a cold, depressed feeling directly. With regard to the details of gyp-rooms, coal-boxes, and so on, all these ingenious contrivances were absolutely Mr. Lock's, and if everybody had his due, certainly Mr. Lock's name should be on that plan as well as the architect's. He settled the general disposition of the rooms, and all the other details. He (the President) entirely agreed with Mr. Prior that the architect's business was not entirely to override his client, but to work with him. All reasonable architects were only too glad to get the suggestions of those who were going to use the buildings, and who must very often know their requirements better than the architects did. In this case Mr. Lock suggested the greater portion of these arrangements, and the part he was responsible for turned out extremely well. There were other details he wished he had gone a little further into. At a modern college there ought to be baths. He thought so then, and had impressed it upon the authorities, and he was glad to hear there would be baths later on. He also thought hot-water should be laid on to each floor. Why it should

still be cooked in kettles to the great danger of the undergraduates and the buildings generally he could not conceive. There were also certain sanitary annexes which he did not think should be absolutely abolished from even University buildings. There was one point touched on in the Paper he should like to say a word about. Mr. Lock in his concluding observations was rather severe on architects when he begged them not to think only of the outside of the buildings, and he ascribed to him (the President) a remark counselling architects not to put *all* they knew into the façade. He no doubt said such a thing, but he did not remember making that remark. It was, however, a curious thing that the public should still think that architects thought only of the front, and took no trouble about the inside at all. The peculiar thing was that most architects would say that the tendency of architects at the present day was to think a little too much of the inside and less of the front. He was quite sure that the development of plan in these days has grown more rapidly than the development of character in the architectural work they were carrying out. He hoped Mr. Lock would take it from them that architects did think of the inside, and that they quite agreed with him that a building to be worthy must be fitted for the purposes for which it was to be used. They were greatly indebted to Mr. Lock for his Paper.

9, Conduit Street, London, W., 21*st May* 1904.

CHRONICLE.

Board of Architectural Education.

The Council have appointed a Committee that will be constituted as a Board of Education, to whom it shall be a reference, with a view to the consideration of the various schemes of Architectural Education throughout the United Kingdom, to draw up and submit to the Council a uniform scheme of Architectural Education, and to approach the recognised institutions of architectural training with a view to its general adoption.

The Board is to have full power to conduct its own negotiations for the purposes of the above Report, but shall not, without special Resolution of the Council, involve the Institute in any expenditure. The Board is composed of *Members* and *Advisory Members*.

The *Members* are 16 representative architects, of whom at least 10 are to be members of the Institute. Of these architects three are to be selected by the Council, and are to include its President. Two (being members of the Institute) are to be selected by the Committee of the Architectural Association, and are to include its President. The remaining 11 are to be appointed in the first place by the Council and afterwards co-opted by the Board.

The *Advisory Members* are to be representatives of the Royal Academy, University of London, University College, King's College, the Board of Education, the Architectural Schools of Liverpool and Manchester Universities, and of Leeds, Birmingham, Edinburgh, Dublin, Cardiff, and of such others as may afterwards be determined by the Board.

Board of Professional Defence.

The President, at the General Meeting last Monday, announced that the Council, after very careful consideration, and after the matter had been reported upon by a Committee, had decided to establish a Board of Professional Defence. The work of the Board would be to consider any case submitted to it by a member of the Institute, and report to the Council whether it would be in the interests of the profession generally for the Institute to support the member. The Board would have authority from the Council to take solicitor's or counsel's opinion on any case to enable it to report. In France, continued the President, architects had long possessed such a Board, and it was considered that architects in this country should have something of the same kind. The Council had only decided the matter that afternoon, and in due course there would appear in the Journal particulars of the formation of the Committee, and the conditions under which members of the Institute would be able to apply to it for legal assistance.

The Registration Question.

The following letters have been handed in for publication:—

64, *Cross Street, Manchester, 4th May* 1904.

W. J. Locke, Esq.—

Dear Sir,—I have recently received a letter from Mr. W. Gillbee Scott, of 25, Bedford Row, London, respecting the R.I.B.A. Election.

His letter asked if I was in favour of the

Registration and Statutory Qualification of Architects, and asked me if I desired to have my name included upon a certain list of candidates for election, would I sign an enclosed form. I have not signed the form, because I think such action as they are proposing to take does not agree with my ideas of what should be done. I dictated a letter to Mr. Scott, copy of which I enclose herewith. I send this to you so that my position in the matter may be quite clear. I decline to sign Mr. Gillbee Scott's circular whether the result is that I remain on the Council or whether I do not.

I also send you a copy of my letter to Mr. Scott sent on 4th May (to-day).—Yours faithfully.

CHAS. HEATHCOTE.

(*Copy.*)

W. G. Scott, Esq.— *3rd May* 1904.

DEAR SIR,—Replying to your letter of 28th April, I am an ardent supporter of the principle of compulsory examination prior to a man being qualified to practise as an architect. This is at present called "Registration." I am distinctly in favour of the Statutory Qualification of Architects. But whilst reiterating this, and acting in the Council to the best of my ability to carry the proposal into effect, I do not consider the action of the independent "London Committee," of which you are the Honorary Secretary, is such as to strengthen our hands on the Council. There are many members of that Institute Council whose abilities have deservedly gained them their eminent positions as architects, whose opinions are known to have recently been strongly opposed to the Registrationists, but who have given patient, careful, and unbiassed attention to our opposite views, and have agreed with us in the advisability of something being done to improve the status of architects.

To fully discuss this important matter the Council, as you know, was enlarged by the addition of representatives from every Allied Society. At the very full meeting of this augmented Council-Committee, the subject was treated by every side in a liberal, business-like, level-headed manner, and many presumed differences seemed to vanish on being touched. It will be a thousand pities if an outside Society endeavours to force the pace. As a Registrationist I deprecate your suggestion. The work done already by the present men is excellent. If actual Registration be not the immediate outcome it is already assured that the status of the profession will be much raised in the early future.

I fully appreciate the *motif* of your Committee, and know you have only the best interests of the profession at heart. You consider your proposed course of action is the right one to pursue. It is in this I beg to disagree with you. If such procedure be carried through it will result in splitting the profession into two hostile camps, disadvantageous to any idea of "improved status" or anything else worth having. I ask you, in all sincerity, to reconsider this proposal, and to give the present Council-Committee at least the credit for earnest, thoughtful, honourable consideration of a very difficult subject.

I am personally unable to go further with you than indicated in this letter, and beg to remain, yours faithfully,

(*Signed*) CHAS. HEATHCOTE

(*Copy.*)

W. G. Scott, Esq.— *4th May* 1904.

DEAR SIR,—I wrote to you, under date 3rd May, my views respecting the R.I.B.A. Council and Registration. This letter you will have received to-day. Yesterday, 3rd May, you wired to me as follows:—

"Will name you as supporter of Registration unless you wire contrary.—SCOTT."

I was out of town yesterday and did not personally see that telegram until this morning, 4th May. The telegram was opened at my office in my absence, and the following answer was sent to you in my name:—"I support Registration, but prefer that the matter be dealt with by Council alone. Letter follows.—HEATHCOTE."

I only personally saw that answer this morning, and it is perfectly correct as far as it goes, but so that there shall be no misunderstanding upon this matter, I wish it to be distinctly understood by you and your Committee that I am not a party to your sending out the list of candidates named, and I decline to sign your circular. I consider the Council are doing their very best in this matter, and that your action is most inadvisable, for reasons stated in my letter of 3rd May.—Yours faithfully,

(*Signed*) CHAS. HEATHCOTE.

Obituary.

At the meeting last Monday the decease was announced of Norman Michael Brown, of Newport, Mon., *Associate*, elected 1887, author of the selected design for the proposed Technical Institute at Newport; Francis William Tasker, elected *Associate* 1874, *Fellow* 1903; George Henry Birch, elected *Associate* 1875, and recently retired.

The HON. SECRETARY (Mr. Alex. Graham, F.S.A.), in making the above announcement, observed that Mr. Tasker was recognised by all not only as a very estimable man, but as a very good architect. His works generally were well known to architects, and his so recent election as a Fellow made them regret the more the loss to their ranks of one who gave promise of attaining the highest distinction in his art. George Henry Birch, F.S.A., who died on the 10th May at the age of sixty-two, had been Curator of Sir John Soane's Museum in Lincoln's Inn

Fields since 1894, having succeeded the late Mr. Wyatt Papworth. The son of the late Dr. Samuel Birch, the distinguished Egyptologist of the British Museum, he was born in 1842, and was articled to Mr Charles Gray, architect, in 1858, being subsequently with Sir M. Digby Wyatt and Mr. Ewan Christian. He became President of the Architectural Association in 1875, and was the hon. secretary of the London and Middlesex Archæological Society from 1877 to 1883. Mr. Birch designed the Old London Street in the Health Exhibition, and was Cantor Lecturer to the Society of Arts in 1883, and vice-president of the St. Paul's Ecclesiological Society. He published *The Old House in Lime Street, City*, and *The Churches of London in the Seventeenth and Eighteenth Centuries*. He took a deep interest in the antiquities of the metropolis, and formed a valuable collection of London prints and drawings. Mr. Birch, Mr. Graham said, was a diligent student of architecture all his life, and nobody who had ever held that important and desirable post of Curator of the Soane Museum could have fulfilled the duties in a more excellent way than Mr. Birch. The Trustees would have great difficulty in finding a man equal in all respects to their late lamented colleague.

THE PRESIDENT said that Mr. Tasker and Mr. Birch were very old friends of his and of many other architects in that room and elsewhere. Mr. Tasker was a member of the Architectural Association. He was a man of singularly outspoken and determined views, both on art and on other matters. In the days when they were together at the Association Class of Design they used to criticise each other's works very candidly. From Mr. Tasker perhaps they heard the most candid criticism of all; he was a man who always spoke his mind, which is what Englishmen like; but he spoke it without any bitterness, and left no ill-feeling behind. He was a Catholic, and was fortunate in being the nephew of Miss Tasker, a most benevolent member of that Church, and this relationship secured to him early in life many important commissions. One of the earliest was the College in St. Charles' Square at Notting Hill, and when Miss Tasker died he had given such proof of his ability that to the end of his life he always had sufficient work from the Church to which he belonged. He himself always looked upon Mr. Tasker as an architect of remarkable ability, as one capable of building a cathedral had the opportunity ever come to him. He hoped his son, whom he knew very well, would be able to succeed him. George Henry Birch, whose funeral took place on Saturday, the President said was also a great friend of his and of many others who were at the Association at the same time. Tasker and Birch were there together. Birch was a man who gave himself from his youth to archæological pursuits in connection with architecture, and perhaps the work he would be best remembered by would be the "Old London" he created at Earl's Court. Now, of course, anyone could produce an "Old London"; but Birch was the first to do it, and it had never been done so well by anyone else. Birch belonged to a small coterie of which he (the President) was one, and for over five-and-twenty years they met month by month at each other's houses to sketch and draw—and one gets to know a man very well under those circumstances. He remembered Birch explaining his idea of Old London, and from the point of view of archæological research and truth it was most excellent, and at the time entirely new. He did also a good deal of literary work. *London Churches of the Seventeenth and Eighteenth Centuries*—perhaps the best known of his works—was a very valuable production, giving not only photographs but a complete list and description of the various buildings represented. He built a very picturesque little church at Dartmouth, but owing to lack of funds it was never developed as fully as his talent would have enabled him to do. As one of the Trustees of the Soane Museum he (the President) had come in contact with Birch as Curator, and he should like to testify to the great obligations the Trustees were under for the loving care and attention he gave to that Museum, and for the efficiency to which he brought it. The visitors largely increased during his curatorship. He made himself thoroughly acquainted with the contents of the Museum; he was always there, and was always willing to give of the information he possessed. It was a great regret to them all to lose these gentlemen from their ranks.

THE ARCHITECTURAL ASSOCIATION.

THE Association are now fairly installed in their new home in Tufton Street, Westminster. The President (Mr. H. T. Hare) and Committee held their first reception there on Tuesday, the 10th inst., when a large number of members and friends had an opportunity of perambulating the building and observing the comfortable conditions under which the functions of the A.A. teacher and student will for the future be discharged.

Details of the transference to the Association of the premises of the Royal Architectural Museum and Westminster School of Art will be found in the JOURNAL for 22nd November 1902. The transfer carried with it the valuable collection of casts belonging to the museum, and the Association undertook, if the Royal Assent were given, to retain the name "Royal Architectural Museum," and to keep the museum open to the public.

The Association, as the premier architectural

teaching body in the United Kingdom, had long outgrown their accommodation in Great Marlborough Street. For years they had searched in vain for premises adaptable to their needs, and they had at length resolved to look out for a convenient site and build premises of their own. Building and equipment would involve a cost of at least £20,000, and practically the whole amount would have to be raised by the contributions of friends. A subscription list was opened in 1901, which the Association itself headed with £1,000, and by the end of the year some £2,000 more had been either given or promised. The Institute recently subscribed £500. An attempt was made by means of an influentially signed appeal in *The Times* to win the sympathy and support of the general public. The result was not encouraging; it became evident that what had to be done must be done by architects themselves. The possibility of the Institute and the Association joining in a building scheme was then discussed. A joint committee of the governing bodies considered the proposal, and reported in its favour, it being understood that the two institutions should occupy one site and have some of the accommodation in common, but that the respective premises should be to all intents and purposes separate buildings. Two members of the joint committee were commissioned to find a site. The practicability of the scheme was reserved for consideration when the site should be forthcoming. Meanwhile the Association had started the day school, and their needs were becoming daily more and more pressing. It was felt that unless suitable accommodation were almost immediately in prospect, the educational work of the Committee would be seriously affected, if it did not collapse altogether. As Mr. Aston Webb remarked at the reception in Tufton Street last week, the A.A. Committee were at their wits' end to know what to do, when the offer of the Museum arrived to put an end to their perplexities and lead to perhaps the most satisfactory of all possible solutions of the problem.

The transfer of the premises, with fixtures, fittings, and furniture—practically a free gift of the whole—took effect in March last year, and the work of remodelling and supplementing the buildings to fit them for their new requirements was at once put in hand; and very successfully has it been carried out by a former President of the Association, Mr. Leonard Stokes. It may be mentioned that the original cost of the Museum building was over £4,000, and of the School of Art studios £3,000. The combined annual rent is £250. The collection of casts is valued at some thousands. The Museum itself—a dreary place in the old days—will gain something in attractiveness from its new environment; and the public who visit it, presumably having some fancy for architecture, may come in time to sympathise with the great aim of the Association—viz. to give its students the best possible training in the art and science of architecture—and so help to make it more widely known and appreciated.

The alterations and additions to the premises, with expenses incidental to the transfer, have brought the outlay up to over £10,000; and at the date of writing the Association are in debt to the extent of at least £5,000.

The Association have at last a home worthy of their aspirations, and as a consequence a widely extended sphere of usefulness opens out before them. But their efforts will be hampered by such an expensive burden of debt. The architect's is not a lucrative profession for the vast majority. That £3,500 has been raised among them speaks much for their vitality and public spirit. Seeing how greatly the community stands to gain by a highly trained and efficient body of architects, it would seem eminently a case for a grant out of the public funds available for technical training. It appears vain, however, to hope for help from this source—nor perhaps is it altogether desirable. It may be better and more fitting that ways and means be found within the profession itself for clearing off the debt. What the Association have achieved by their own efforts will doubtless stimulate them to still greater exertions; and, to quote Mr. Webb again, "the older architects must take care to see them through their difficulties."

The Association held their Annual Dinner—a numerously attended and very agreeable function—on the 13th inst., and Mr. Hare took the opportunity to render acknowledgment to those who have helped to bring about the great change in their prospects. They had, he said, several very good friends to thank for what had taken place. First, they must not forget the very important work done by his predecessor in the chair, Mr. W. H. Seth-Smith, for it was largely due to that gentleman's energy and initiative that the Association were in a financial position to avail themselves of the offer made by the Council of the Royal Architectural Museum through Mr. Maurice B. Adams. If they had not possessed the funds Mr. Seth-Smith's energy has supplied them with they would probably have been obliged to decline the offer. The best thanks of the Association are also due to Mr. Maurice B. Adams for the part he took in bringing the matter to a head, and to Mr. Leonard Stokes for the manner in which he has rendered the premises suitable to the needs of the Association.

MINUTES. XIV

At the Fourteenth General Meeting of the Session 1903–4, held Monday, 16th May 1904, at 8 p.m.—Present: Mr. Aston Webb, R.A., F.S.A., in the Chair, 18 Fellows (including 4 members of the Council), 15 Associates (including 1 member of the Council), 1 Hon. Associate, and visitors: the Minutes of the Meeting held 2nd May [p. 371] were taken as read and signed as correct.

The Hon. Secretary announced the decease of Norman Michael Brown, *Associate*, elected 1887, of Newport, Mon.; Francis William Tasker, elected *Associate* 1874, *Fellow* 1903; George Henry Birch, a past *Associate*, elected 1876.

The President announced the establishment by the Council of a Board of Professional Defence, and also of a Board of Architectural Education.

The following candidates for membership, found by the Council to be eligible and qualified according to the Charter and By-laws, were recommended for election:—As FELLOWS, Thomas Arnold (*Assoc.* 1867) (Edinburgh); Walter Albert Catlow (Leicester); Max Clarke (*Assoc.* 1880); Allan Ovenden Collard (*Assoc.* 1889); William Henderson Duncan (Rochdale); Edward Goldie; Alfred Henry Hart (*Assoc.* 1890); Charles Grove Johnson (Mexico); William Campbell Jones (*Assoc.* 1888); William Alfred Large; Thomas Edward Marshall (Harrogate); John Campbell Turner Murray; John Henry Phillips (Cardiff); Alfred Roberts; William Rushworth; Percy Burnell Tubbs; John Collingwood Tully (*Assoc.* 1882) (Cape Town, South Africa); Benjamin Woollard (*Assoc.* 1889). As ASSOCIATES, Charles Rosenthal (*Qualified as Assoc., Colonial Exam. Sydney N.S.W.* 1903) (Sydney, N.S.W.); Herbert Alfred Hall (*Probationer* 1899, *Student* 1900, *Qualified* 1903). As HONORARY ASSOCIATES, James Jebusa Shannon, A.R.A.; Lord Stanley of Alderley. As HON. FELLOW, The Right Hon. Lord Curzon of Kedleston, G.M.S.I., G.M.I.E., Viceroy of India.

A Paper by the Rev. J. B. Lock, Bursar of Gonville and Caius College, Cambridge, on THE PLANNING OF COLLEGIATE BUILDINGS, having been read by the author, and discussed, a vote of thanks was passed to him by acclamation.

The Chairman announced that the adjourned discussion on the Plenum System of Ventilation would take place at the Meeting of the 6th June. Also that a Special General Meeting would be held the same day with reference to an addition to By-law 3 to be proposed by the Chairman.

The proceedings then closed, and the Meeting separated at 10 p.m.

ALLIED SOCIETIES.

DEVON AND EXETER SOCIETY.

At the annual meeting of the Devon and Exeter Architectural Society, held on the 14th inst., Mr. A. S. Parker [*F.*], the retiring President, in the course of his address recalled that they were the first provincial society to be allied to the Royal Institute of British Architects. The foresight and sound judgment then shown by the Society were subsequently endorsed by the alliance of sixteen other societies in Great Britain, Ireland, and the colonies to the representative body in London. The benefits of such a communion were too manifest to need exposition. They were also the first society to suggest to the London Architectural Association the extension of their teaching to the provinces, in conjunction with the local societies; the suggestion had been favourably received, and might lead to a favourable result in the future.

With regard to architectural education, which formed one of the principal subjects of discussion at the conference held at the Royal Institute of British Architects last year, and which he attended as representative of this society, he had strongly felt for a considerable time that the present system of pupilage, with the more or less feeble architectural instruction given at many technical colleges, was an extremely slow and inefficient means for modern equipment for such an art as theirs. There was a real need for a thorough course of art and technical instruction for students outside the routine of office work, combined with the mutual enthusiasm and friendly rivalry which could only be obtained by a class communion of students. All architects should assist to bring about a system whereby students may obtain a semi-collegiate training as a supplement to the system of pupilage. They could not expect public educationists to further their cause unless they themselves showed a strong desire and cause for such advancement. It should be a matter of congratulation to them that they had arranged with the London Architectural Association that students connected with the Devon Society would be able to join the Association's design class in the ensuing session.

As to the question of a compulsory examination by the Institute of all who wished to become architects, and the necessary registration of those architects now in practice, this was a question nearly half a century old, but within the last twelve months it had attained the position of "a burning question." It was quite evident by the votes and resolutions of the various societies that provincial architects were overwhelmingly in favour of the principle. He had the honour to represent the society on the Special Committee of the Institute now considering the question, and had attended the first meeting a few weeks ago. The question was received in a fair and open manner by all the members, and a sub-committee was appointed to draw up some scheme to be submitted to the next meeting for further discussion. The subject being *sub judice* he would not make any special comment upon it beyond that he believed that, should a satisfactory bill be agreed on and carried, architectural education would progress with rapid strides. A large number of students would not enter for the Institute examinations because they were not compelled, and their education suffered accordingly.

All architects must rejoice at the result of the recent judgment of the House of Lords in the case of *Colls* v. *Home and Colonial Stores*, whereby a portion of the question of ancient lights had been set at rest. Through a lack of definition,

the law of ancient lights had always been a source of litigation and a hindrance to building development. There was still room for improvement in the law, and he hoped the time was not far distant when no newly formed lights would be able to claim the rights of easement. In many parts of the country a call for some revision of the Building By-laws had been made with the object of classifying the regulations of the model code, so as to overcome the evils which necessarily accrue to "cast iron" rules having no qualifications.

He hoped the Society would use their best endeavours to prevent the demolition of ancient buildings of interest. The public should be educated to set a proper value on the remaining landmarks of historic interest, which once destroyed can never be replaced. Exeter would have vastly gained had not vandalism in the past been allowed to remove large numbers of ancient buildings, which would have greatly added to the interest of the city, and have been of commercial advantage in the attraction of a larger influx of tourists and visitors. He remembered two especially fine ancient houses in North Street having been removed for the widening of the street, which could have been attained by allowing the pavement to run under the upper stories, on the principle of the Butterwalk at Dartmouth; but no thought or ingenuity appeared to have been exercised. He was pleased to note that the Exeter Chamber of Commerce had decided to fix tablets on places of historic interest in the city. He himself had read a Paper making suggestions in detail to that effect before a special meeting convened by the Chamber of Commerce in 1893.

In briefly reviewing the public buildings completed or in course of erection during the past year within the province, the completion of Truro Cathedral at once called for congratulation to the Church and people of Cornwall, for being the means of producing, within a comparatively short period, a great and beautiful creation of architecture for the worship of God and for the use, uplifting, and delight of many generations to come. It was a remarkable fact that Cornwall had achieved what had not yet been achieved in other and richer parts of the kingdom. The original Cathedral Committee were fortunate in the choice of an architect in the late J. L. Pearson, R.A., as one who was able to recreate the very spirit of mediæval work. The Royal Naval College at Dartmouth was another building of national importance now in course of erection within our province. They had the pleasure of inspecting this great building in its transitory state in September of last year, under the personal guidance of the distinguished architect, Mr. Aston Webb, R.A., who most courteously placed his time at their service. The College when completed would fully justify the selection of the architect by the Admiralty.

As to the future of architecture in this country, he believed there was hope for a fuller and richer development than ever before, owing partly to the continued expansion of wealth and more particularly to the revised system of art education. Fortunately the fetish held during the greater portion of the nineteenth century, that new buildings must be a slavish copy of some particular "style" pertaining to a period not their own, had now been practically abandoned, partly by the diversity of modern requirements, and partly by a new school of design which had been growing during the last twenty years, which set the expression of the purpose for which the building was intended as the motive which should govern its appearance. This doctrine still needed cultivation and development as the goal for correct design. Another trait which was being developed by architects of artistic temperament was simplicity and restraint in design, in contradistinction to the vulgar ideal that architecture consisted of ornament applied to otherwise plain structures. There could be no greater misconception than this. The science of good planning, combined with the use of the three materials stone, timber, and metal, openly shown in well-proportioned constructive lines and freely proclaiming the use for which the building was intended, were the elements out of which true architecture must be made. In addition to the cultivation of art, which should be born in an architect, the great diversity in the requirements of modern building required the closest application to master even a portion of an architect's studies. Such buildings as hospitals, asylums, theatres, churches, business premises, and warehouses, with their attendant modern steel construction, markets, town-halls, libraries, schools, and colleges, were constantly in a state of evolution, each needing special application of systems of heating, ventilation, and electricity. These subjects were all supplementary to the groundwork of construction and to the knowledge of historic architecture and ornament of past ages, and to the cultivation of architectural design. Only the very best culture and thought should therefore be applied to the creation of their art.

NOTES ON THE STRESSES IN FRAMED SPIRES AND DOMES.

By W. Dunn.

THE following notes were put together at a time when I was engaged in the design of a tower.

I found that while the stresses in structures with all the members in one plane, such as roofs and girders, are fully dealt with in writings on construction, very little has been written on that large class of structures wherein the members are in different planes. The subject is naturally more complicated, but by attacking the problem in the simplest form first, one is led on to the more difficult cases that occur in practice.

We cannot fix the sizes of the various parts of a structure without a more or less exact knowledge of the stresses to which these will be subjected, and I should be very pleased if the consideration which I have given to the subject were in any way helpful to others engaged on similar work or interested in similar questions.

VERTICAL AND SYMMETRICAL LOADS ONLY.

1. If we consider a plane frame formed of two upright and two horizontal bars $a\,b$, $d\,c$, and $a\,d$, $b\,c$, loaded, at b and c, with any weights, as in fig. 1, it is evident that, whatever be the loads, they are borne directly by the bars $a\,b$ and $d\,c$, and that they produce no stress in the horizontals $a\,d$, $b\,c$.

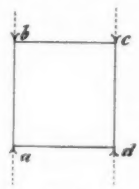


FIG. 1.

2. Suppose now that the supporting bars are inclined at equal angles to the horizon, and that the loads are equal (fig. 2). Draw to some scale the centre lines of the frame (i) as shown by the strong lines, and the lines of action of the loads, and supporting forces, as shown by the dotted lines. Letter each space so that we may identify each *bar*, *load*, or *reaction* by the two letters of the adjoining spaces; thus the horizontals are $c\,e$ and $a\,e$, the inclined bars $b\,c$ and $d\,e$, the loads $b\,c$ and $d\,c$, and the reactions of the supports $a\,b$ and $a\,d$. Lay off to some scale of tons, cwts., or lbs. (ii) the loads $b\,c$, $c\,d$ as in the figure. Consider the joint where the bars $b\,e$, $c\,e$, and the load $b\,c$ meet. From the ends of $b\,c$ in (ii) draw lines parallel to $b\,e$, $c\,e$, identifying their intersection by the letter e. Then $b\,e$, $c\,e$ in (ii) measured to the same scale to which we have drawn $b\,e$ represents the stress in $b\,e$, $c\,e$. To determine the nature of these stresses draw a small circle, as in (iv), with the lines $b\,e$, $c\,e$, and $b\,c$ radiating in the proper directions from it, and sketch the triangle of forces $b\,c\,e$ alongside. The direction of $b\,c$ is known, being downwards; attach the arrowhead to it, and put arrowheads to the other two sides of the triangle, so that they follow round in cyclic order. Then on the lines radiating from the circle put corresponding arrowheads; as the arrows point *toward* the circle the bars $b\,e$, $c\,e$ are both in compression.

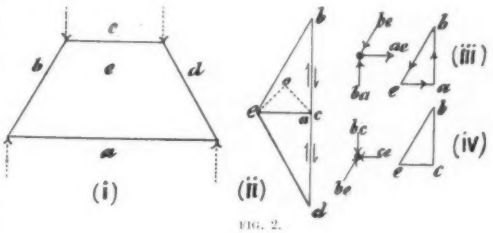


FIG. 2.

Next consider the joint formed by the meeting of $a\,e$, $e\,b$ and $b\,a$. Knowing the amount and direction of $b\,c$ in (ii) we draw from the ends of it lines parallel to $b\,a$ and $a\,e$; these coincide with $b\,c$ and $e\,c$. Sketch the circle and radiating lines, and the triangle of forces as before (iii); knowing that $a\,b$ acts upwards, affix the arrowheads in cyclic order in the triangle, and transfer them to the lines radiating from the circle; $b\,e$, as before, points *towards* the circle, and is in compression, but $a\,e$ points away from it, and is in tension.

3. Take next the frame shown in fig. 3 (i)—also a plane frame—loaded by vertical weights at each joint, the loads being equal on each side. Letter the spaces as before and lay off (ii) $b\,c$, $c\,d$, $d\,e$, $e\,f$, $f\,g$, upon a vertical line. Beginning with the load $d\,e$, resolve it along the bars $d\,j$, $j\,e$ by drawing lines from the ends of $d\,e$ (ii) parallel to these

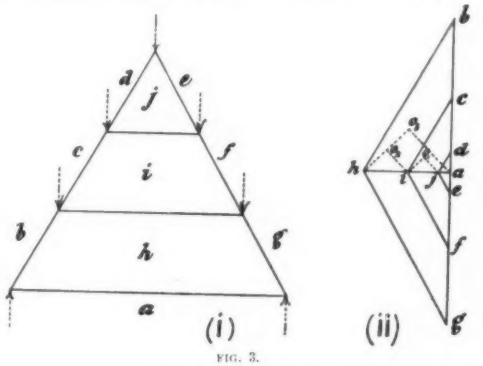


FIG. 3.

bars, and meeting in the point j. Proceed similarly with the rest of the frame until the stress diagram is completed; then, as before, the stresses in the bars of the frame in (i) are shown by the length of the corresponding lines in (ii), measured to the scale of tons, cwts., or lbs., to which the loads $b\,c$, $c\,d$, &c., were laid off.

4. Fig. 4 (i) shows another form of plane frame. As it is symmetrical, and the loads are also symmetrical, we have only made the stress diagram for one half, the other half being similar. These loads are supposed applied at the joints, and the lines of action are shown by dotted lines.

Begin by lettering the spaces; then lay off the loads in (ii) to any convenient scale, as shown by $a\,b$, $b\,c$, $c\,d$, $d\,e$. From the ends of $a\,b$ draw lines parallel to $a\,j$, $b\,j$, and letter the intersection j. Proceeding to the next load, we have the amount and direction of $b\,j$, $b\,c$; from j and c, draw lines parallel to $j\,i$, $c\,i$, lettering the intersection i, proceeding thus until the diagram is completed.

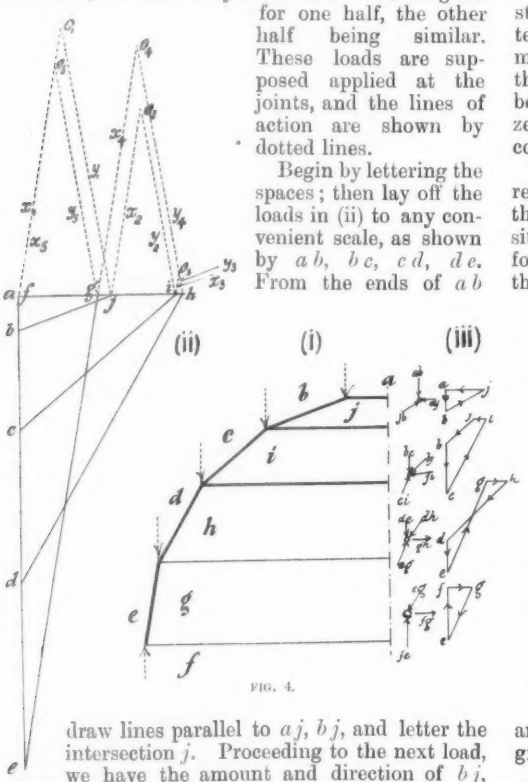


FIG. 4.

In (iii) the sketches (not drawn to scale) show the method of determining the nature of the stresses, the thick lines in (i) showing the pieces in compression, and the thin lines the pieces in tension.

5. Before we leave these plane frames, consider the effect of altering the shape of the frame without altering the loads. If, in fig. 2, the slope of $b\,e$, $e\,d$ be made flatter, the stress in these bars, and in $c\,e$, $a\,e$ is increased; if the slope be made steeper, the stresses are correspondingly diminished until when $b\,e$, $e\,d$ become upright the stress in these is equal to the loads, and the stresses in the horizontals disappear. Similarly, in fig. 3, if the loads remain constant, while the slope of the raking bars is made flatter, the stresses in these, and in the horizontals, are increased, while the stresses are diminished if the slope is made steeper. In fig. 4 the dependence of the stresses on the inclination of the bars is made evident. Thus the stress in $h\,g$ is a tension; but by making $g\,e$ less steep the stress in $h\,g$ can be made equal to zero, or become a compression.

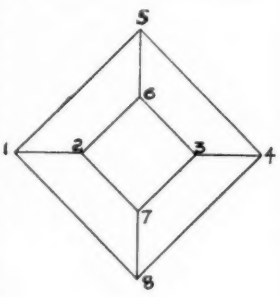


FIG. 5.

6. Let fig. 2 (i) represent a section through two opposite angles of the four-sided square frame shown in plan in fig. 5, the loads on the points 2, 3, 6, 7, being equal to each other, and to $b\,c$ or $c\,d$ in fig. 2 (ii). Then the latter figure shows the stresses, excepting that as the stresses along $c\,e$, $a\,e$ are not resisted by single bars, but are resolved along the lines 1 8, 1 5, and 2 7, 2 6, respectively, the stresses $c\,e$, $a\,e$ are to be resolved into components parallel to those lines. From e and c, therefore, draw lines parallel to 1 8 and 1 5 (that is, at angles of 45 degrees) to meet in 0; then $o\,e$, $o\,c$, measured to the scale to which $b\,c$, $c\,d$ is plotted, give the stresses in 1 8 and 1 5, or 2 7, 2 6. As the frame is equally loaded at 2, 7, 3, and 6, there are equal and opposite reactions at all the points of the frame on this level.

7. If fig. 2 (i) represented a section through two opposite angles of a regular polygon, say, of eight sides, as shown in plan in fig. 6, the lines $e\,o$, $c\,o$ would be drawn parallel to the sides of that octagon 1 2 and 1 8 (that is, at angles of $22\frac{1}{2}$ degrees).

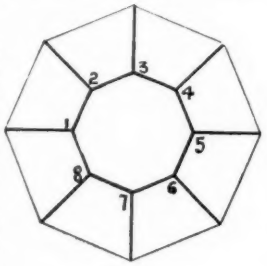


FIG. 6.

8. If, instead of a plane figure, fig. 4 is taken as a central section through opposite angles of a polygonal dome, formed of ribs and rings, the plan of which is shown in fig. 7, then the same stress diagram applies; but as the bars $f\,g$, $g\,h$, $h\,i$, $i\,j$, and $j\,a$ are replaced by ribs or rings the corresponding stresses must be resolved along lines parallel to these ribs or rings, as x and y in fig. 7. This is done by making $a\,o_1$, $j\,o_1$, &c., in fig. 4 (ii) parallel to x_i and y_i; $a\,o_1$, $j\,o_1$ show

then the stresses in the top ring. Note that these act in a plane at right angles to the others—*i.e.* in a horizontal plane. As all the loads are symmetrical, all the corresponding bars have the same stresses.

9. This example indicates the general nature of the stresses in domes, which stresses we may divide into two classes: namely, stresses acting in vertical planes which are always compressive, and stresses acting in horizontal planes which are

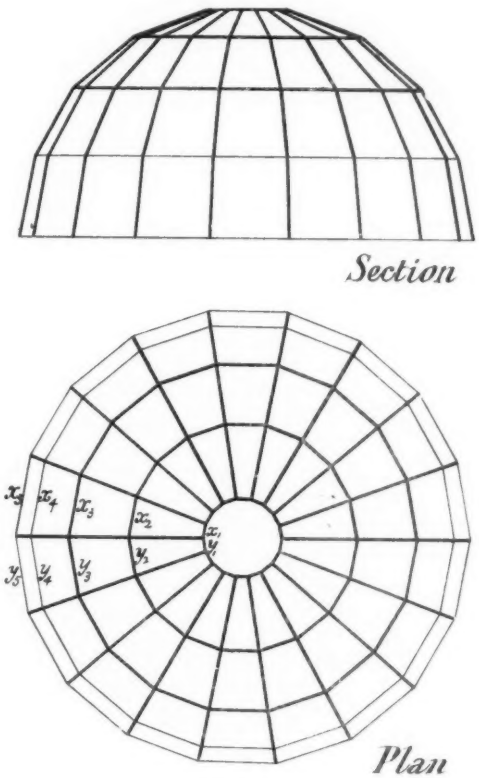


FIG. 7.

usually tensile in the lower part and compressive in the upper. The top ring will always be in compression, and the bottom ring in tension.

To show how the stresses may be modified by the loading, assume a heavy lantern upon the top of this roof (fig. 7), and let fig. 8 be the corresponding stress diagram, where $a\,b$ to the previously chosen scale of loads represents that portion of the weight of the lantern bearing upon the half rib; or, as we are dealing with an eighteen-sided figure, one-eighteenth of the weight of the lantern. By completing the diagram we find that all the rings except the top ring are in tension. Without the lantern, and under the loads in fig. 4 (ii), the dome tends to burst out at the first and second or bottom rings, and to collapse inwards at the third, fourth, and fifth or top rings. The effect of adding the lantern is to make the whole dome tend to burst out except at the top ring.

10. It will readily be seen that the loads might be so arranged that all the stresses in the rings, except in the top and bottom rings, would disappear, the stress diagram taking the form shown in fig. 9; or the form of the dome, if the loads were fixed, might be so varied as to produce the same result. Such a dome would be maintained by the united action of the ribs acting as simple arches. The stress diagram shows also that an alteration in any load has no effect upon the ribs or rings above it.

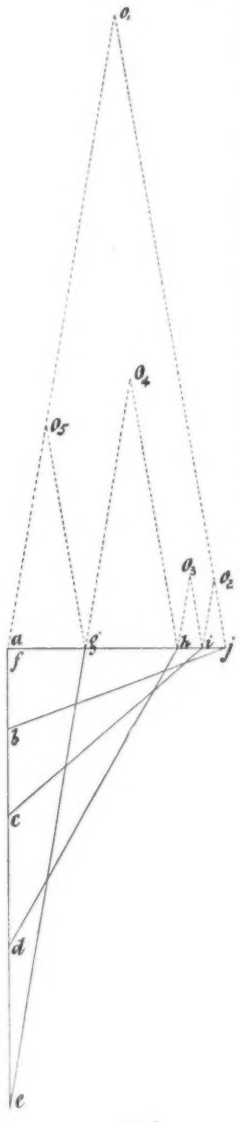


FIG. 8.

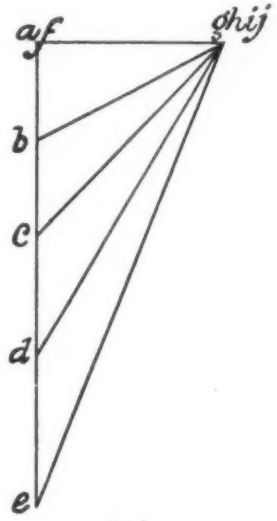


FIG. 9.

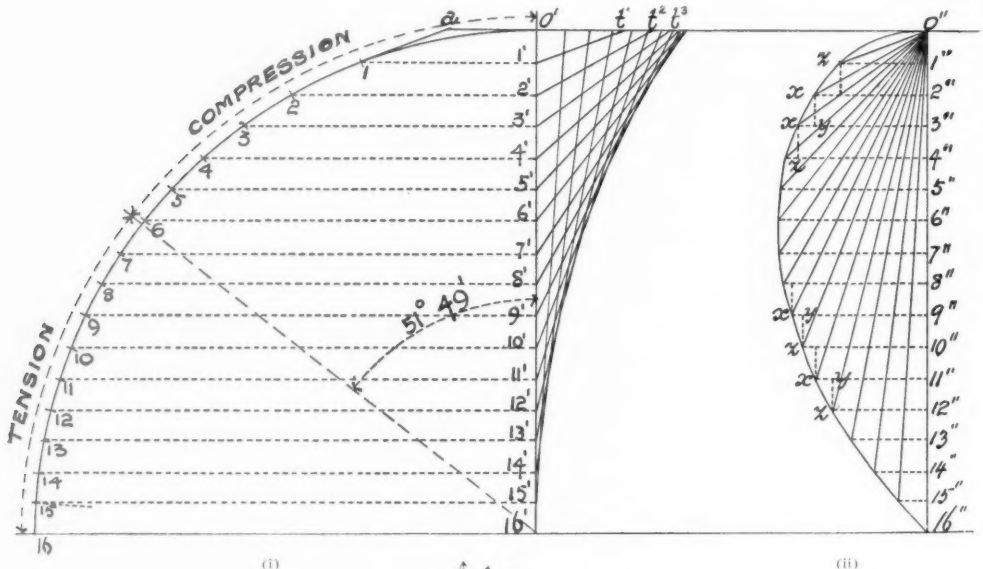
11. If the number of ribs and rings increases indefinitely we approach what Rankine has called the true dome—*i.e.* a thin shell forming a solid of revolution round a vertical axis. This forms the next example. Fig. 10 (i) shows the half-section

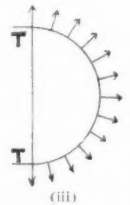
of the dome, which is hemispherical, and of metal capable of resisting tensile and compressive stresses, of uniform thickness, and of uniform weight per square foot.

Assume the centre line as representing to some scale yet to be determined the weight of the dome, or of some section of it. Divide this line into any number of convenient parts—for convenience we have taken sixteen equal parts—and mark the divisions 1′, 2′, 3′, &c. Draw through 1′, 2′, 3′, &c., horizontal lines to cut the section of the dome in 1, 2, 3, &c. Then as the area of any segment of a sphere equals $c\,h$, where c is the circumference of the sphere, and h is the height of the segment, any length, such as 2′, 3′, or 5′, 6′ on the centre vertical, measured on the same scale upon which that vertical represents the whole weight of the dome or the chosen portion of it, will give the weight of the segment 2, 3 or 5, 6 of the dome or chosen portion.

As the thickness of the dome is inconsiderable the pressure may be considered as uniformly distributed over any section, such as 1, and therefore tangential to its surface. Draw through 1 a line 1a tangential to the surface (at right angles to the radius 1′, 16′) and through 0′ produce a 0′ indefinitely. Through 0′ and 1′ draw 0′ t' and 1′ t' parallel to 0′ a and 1 a respectively to intersect in t'; we have then the triangle of forces holding that part 0′ 1 of the dome in equilibrium. 0 1′ is the weight of it (being the load on point 1), the line 1′ t' the direct compression uniformly distributed over the section, and the line 0′ t' the radial thrust, all measured to the same scale (not yet determined) as 0′ 16′.

If the point 1 were taken very near the crown, the load would be very small, and the horizontal thrust and direct stress would also be reduced; at the crown itself there is no stress. This is one of the material points of difference between the dome and the arch, which latter construction has always a thrust at the crown.





(iii)

FIG. 10.

Proceeding to section 2 we form the stress diagram, giving the four-sided figure 1′ 2′ t' t^2, 1′ 2′ being the weight of the segment, 1′ t' the direct stress upon the lower section; t' t^2 giving radial thrust. Proceeding similarly for the remainder of the figure, the direct thrusts cut the horizontal lines further and further from the load line until we reach 6, when the intersections begin to approach the load line again, making the polygon of forces for each section similar to the four-sided figure $g\,h\,d\,e$ in fig. 4 (i).

12. [The diagram of stresses may take another form given at (ii). Set off the load line as before, and through 0″ draw lines tangential to the surface of the dome at the various points to intersect with the horizontal lines. Through these intersections draw the curve from 0″ to 16″. Then we have the stress diagram, but of the form x, y, z, o'', the radial thrusts above the point where the curve turns to the load line again, and the radial tensions below that point being given by the differences x, y.

This radial thrust and tension may be made more clear by referring back to fig. 4, in which aj, ji, ih may be called the radial thrusts, and hg, ga the radial tensions. As in that diagram these thrusts and tensions were resolved along the rings, so in this case the xy's must be resolved into equivalent thrusts or tensions acting at right angles to the plane of the paper; that is actually upon the vertical faces of the section.]

13. Let 0′ 16′ represent the total weight of the dome, then any xy shows the total radial thrust upon the corresponding section, which we shall call R. Being uniformly distributed, its intensity per unit of circumference equals

$$\frac{\text{R}}{\text{units in the circumference}}$$

just as the intensity of pressure on a pillar equals the total pressure divided by the units of area in the pillar.

In any circular ring under uniform normal pressure (fig. 10 (iii)), as in a cylinder holding water, the resultant tension or compression T (which we call hoop tension) equals the intensity of the radial pressure multiplied by the radius,

$$\frac{\text{R} \times \text{radius}}{\text{circumference}} = \text{hoop tension} = \text{T}.$$

This $\frac{\text{radius}}{\text{circumference}}$ is a constant quantity for any circle, and equals $\frac{1}{6{\cdot}2832}$ nearly, so that $\frac{\text{R}}{6{\cdot}2832} = \text{T}$.

When, therefore, 0′ 16″ represents the total weight of the dome, we must divide each xy by 6·2832 for the hoop tension.

Suppose we take 0′ 16″ to represent $\frac{1}{6{\cdot}2832}$ of the weight of the dome, then we will not require to divide the xy's in fig. 10 (ii), or, what is the same thing, the lengths 0′ t', t' t^2, &c. in fig. 10 (i), as they will each equal the hoop tension at that point; *i.e.* if we take, not the weight of 360°, but $\frac{360}{6{\cdot}2832}$ or 57°·3 of the dome, the xy's, or 0′ t', t' t^2 . . . &c., give the hoop tension or compression directly.

Form such a scale that 0′ 16′ measures the weight of 57°·3 of the dome; the lengths xo'' in (ii) measured to that scale give the total compression on a horizontal plane on a segment of 57°·3 of the dome, or the lengths 1′ t', 2′ t^2, 3′ t^3 . . . &c., in (i) may equally be used.

As the length of an arc of 57°·3 equals its radius, we have only to divide the lengths 0″ by the radius at the corresponding points to get the intensity of pressure on the horizontal section.

14. At the joint of no hoop thrust or hoop tension the maximum horizontal thrust is caused. This joint is frequently called the joint of rupture; it is situated at a height above the springing line of $\frac{1}{2}$ ($\sqrt{5}$–1) radius, or about 51° 49′ from the vertical. Above that joint the dome tends to collapse inwards; below it tends to spread outwards.

15. The results in paragraphs 11 to 14 inclusive are assumed by some writers to apply to stone domes of considerable thickness; but they are only correct for *thin* domes of material capable of resisting tension and compression, of true hemispherical section, and of uniform weight per unit of surface. If we put an "eye" to the dome (*i.e.* omit the central upper part—say the part above the line 1 1′) then the horizontal line 0′ t', t^2 t^3, &c., is lowered to the level of 1 1′, and the position of the joint of rupture is also lowered. If a heavy load were put at 1, then it would be raised, increasing the part under hoop tension and diminishing the part under hoop compression. If the section is varied and becomes pointed or of any other curvature, there is also a change in the position of this joint.

16. Note that in the thin hemispherical dome we have been considering (fig. 10) there is no outward thrust upon the abutments.

If the dome is a segment of a sphere less than a hemisphere, *i.e.* if the springing line is not at 16′ 16 in fig. 10 (i), but at the level of say 9′ 9, there is an outward thrust to be taken by the abutments or by a ring at that level. The stress diagram for such spherical dome less than a hemisphere is represented by that part of the stress diagram in fig. 10 (i) which lies above the level 9′ 9, the part of the stress diagram 9′ to 16′ being supposed removed. But while as before the lengths of the type 0 t', t' t^2, t^2 t^3, give the hoop tensions or thrust upon any division above the springing line, there is at that line an outward thrust, which is the horizontal component of the line 9 t^9, and is equal to 0′ t^9. It may make this clearer if we remember that from the crown downwards at each ring or segment, we are constantly adding the horizontal thrusts of the type 0 t', t' t^2 (xy in fig. 10 (ii)), until we come to the joint of rupture or no hoop pressure. At that point the horizontal thrust to be taken by the abutments or by a ring at the base is a maximum, and is the sum of all the 0 t', t' t^2, t^2 t^3 . . . in fig. 10 (i) (or xy's in fig. 10 (ii)); below it the horizontal thrust is still the sum of the xy's, but these xy's change sign, becoming tensions, and act in the opposite direction to those in the upper part of the dome, so that we take the *algebraic* sum. The outward thrust thus diminishes from the joint of rupture downwards until it is zero at the base of a hemispherical dome. For the segmental dome there is always a horizontal thrust at the base, which is the algebraic sum of the xy's. It may be ascertained directly by laying off the vertical line representing the weight of the part considered (say 0′ 9′ in fig. 10), drawing through 0′ a horizontal line, and through 9′ a line tangential to the surface of the

dome at the springing 9, to intersect in t^9; then $0'\,t^9$ is the horizontal thrust to be resisted by the abutments or by a ring at the base. If the load-line $0'\,9'$ represents not the total weight of the dome, but the weight of $\frac{57°{\cdot}3}{360°}$, the line $0'\,t^9$, measured to the scale of loads, gives the tension in the segment at the base.

17. Instead of the resistance to spreading outwards being supplied by a metal ring at the base, it may be given by the stability of the supports, such as a circular wall, or by a series of buttresses.

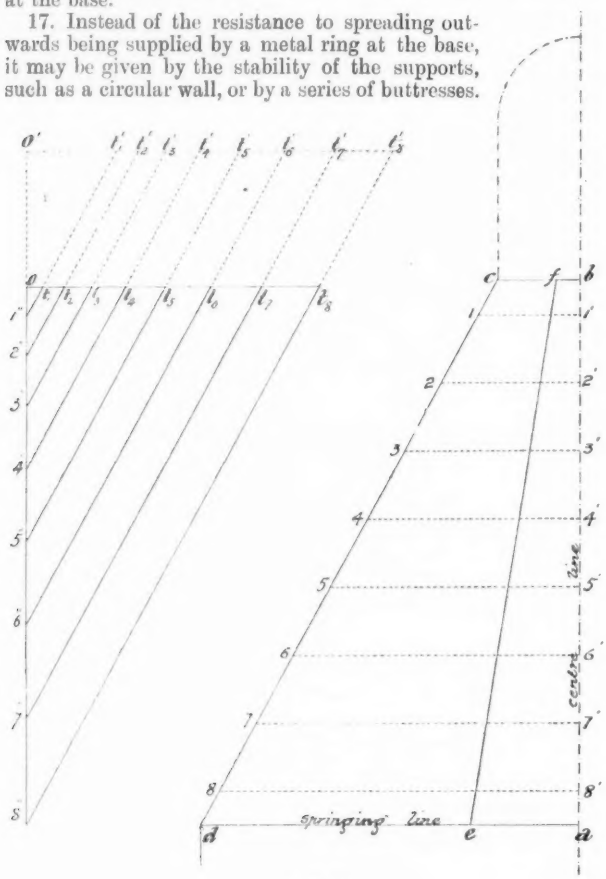


FIG. 11.

In that case it may be desired to know the outward radial thrust rather than the hoop tension. The outward thrust per degree of circumference is given by the line $0'\,t^9$, measured to the scale of loads and divided either by 360° or by 57°·3, according as the load line has been taken to represent the total weight or the weight of $\frac{57°{\cdot}3}{360°}$ of the total.

Rankine gives an analytic solution of this hemispherical dome in his *Applied Mechanics*.

18. Let us now turn to the case of a conical dome also of thin material of uniform thickness, capable of resisting both tension and compression, and let $a\,b\,c\,d$ in fig. 11 be the half central section.

To draw the stress diagram, it is necessary to know the proportionate weights at each part of the height. Divide the height into, say, eight equal parts, and through the centres of these equal parts, 1, 2, 3 . . . . 8, draw horizontal lines to intersect the centre line. Then the lengths of these lines, 1 1′, 2 2′, 3 3′ . . . . 8 8′, are proportionate to the weight of each corresponding division. We can lay off on a vertical load-line lengths equal to 1 1′, 2 2′, 3 3′ . . . . 8 8′ in regular succession, and that vertical load-line would then represent to some as yet unknown scale the weight of the dome, and be divided in proportion to the weights of each corresponding part of equal height. As the full radii would often lead to a stress diagram of too large a scale, we may take proportionate parts of the radii by drawing the line $e\,f$ cutting off, say, $\frac{1}{3}$ or $\frac{1}{4}$ of the lengths 1 1′, 2 2′, &c., and using the radii so reduced.

We use the reduced radii in this case, and accordingly set off from 0 the lengths 0 1″, 1″ 2″, 2″ 3″ . . . . 7″ 8″ equal to the lengths of 1 1′, 2 2′ . . . . 8 8′ cut off by the line $e\,f$. Take the total length 0 8″ to represent the total weight of the dome $\div 6{\cdot}2832$; then the scale for the stress diagram is found by dividing that length 0 8″ into the number of lbs., cwts., or tons contained in

$$\frac{\text{weight of dome}}{6{\cdot}2832}.$$

Next, as in the spherical dome, we have for the stress at 1, the load or the weight of the first of the eight divisions into which we divided the dome, acting vertically, represented by 0 1″; then the resistance offered by the lower part of the dome, which we take as acting in the centre line of the shell, and accordingly shown by a line $1''\,t_1$ parallel thereto. We have also the resistance supplied by the hoop pressure acting horizontally and therefore by the line $0\,t_1$. The triangle $0\;1''\;t_1$ is then the triangle of forces acting at the point 1, and holding the uppermost of the eight divisions in equilibrium.

Take next the point 2. We have acting on the upper face the stress $1''\,t_1$ just found; then the weight of the second division, acting vertically downwards through the point 2, and represented

in the stress diagram by 1″ 2″, then the reaction of the lower part of the dome which is drawn parallel to the slope of the dome as before, and the hoop pressure $t_1\ t_2$, drawn horizontally from the upper end of t_1 1″, to intersect with 2″ t_2. Thus t_1 1″ 2″ t_2 is the polygon of forces for the point 2.

The lengths of the type $o\ t_1\ t_1\ t_2 \ldots\ t_7\ t_8$ give the hoop compressions when the line 0 8″ represents to some scale the total weight of the dome $\div 6{\cdot}2832$. All these hoop pressures act outward, and at the base we have either to supply a hoop tension by means of a metal ring, or a resistance to spreading supplied by the abutments. This hoop tension or resistance must be equal to the sum of all, $o\ t_1$, $t_1\ t_2$, $t_2\ t_4 \ldots$, &c.; in other words, at the base of the dome we should have acting the stress 8″ 0 the vertical reaction of the abutment (equal to the weight of the dome) and a hoop thrust or tension equal to $o\ t_8$. The triangle of the forces acting at d is thus: $o\ t_8$ 8″.

The hoop pressures $t_1\ t_2$, $t_2\ t_3$, &c. are the mean pressures acting on the divisions of the dome to which they apply, and the mean pressure on the material in a plane normal to the vertical section is equal to $t_1\ t_2$, $t_2\ t_3$, &c., divided by the area of the section on which any such hoop pressure acts—*i.e.* the raking length of any division, multiplied by the thickness of the shell of the dome.

19. Suppose now that the dome, instead of having an eye at the top had a load, such as that of a lantern acting at 1. Then in the stress diagram our first load would be represented not by the short line 0 1″, but by some longer line 0′ 1″ which, measured to the scale of loads, would be equal to the load of the lantern, or the load of lantern $\div 6{\cdot}2832$, according as our load-line represented the total weight of the dome or the $\frac{1}{6{\cdot}2832}$ part of it. The changed form of the diagram is shown by the dotted lines, the points $t_1\ t_2 \ldots t_8$ being now found at a higher level, $t_1'\ t_2' \ldots t_8$, and the meridian stresses 1″ t_1, 2″ $t_2 \ldots$ 8″ t_8 being increased to 1″ t_1', 2″ t_2' $\ldots$ 8″ t_8'.

Rankine gives the analytic solution of these conical domes with and without lanterns in his *Applied Mechanics*.

As we have said before, this method of graphical study is equally applicable to any shape of dome. The mathematical method is more or less limited to regular curved outlines.

LATERAL FORCES AND IRREGULAR LOADING.

20. We need not discuss here the question of wind pressure upon surfaces inclined at any angle to its direction; we may refer to the various papers on that subject for the most recent estimates of its values, and by multiplying the exposed area by the corresponding pressure per unit of surface, ascertain the amount to be provided for.

Let the structure shown in fig. 12 be acted on by a wind pressure W, acting at a distance l, above the section $b\,c$; it is required to find the stresses produced by W on the part $a\ b\ c\ d$.

Dealing first with this as a plane figure, we know that W produces on the section $b\,c$, a bend-

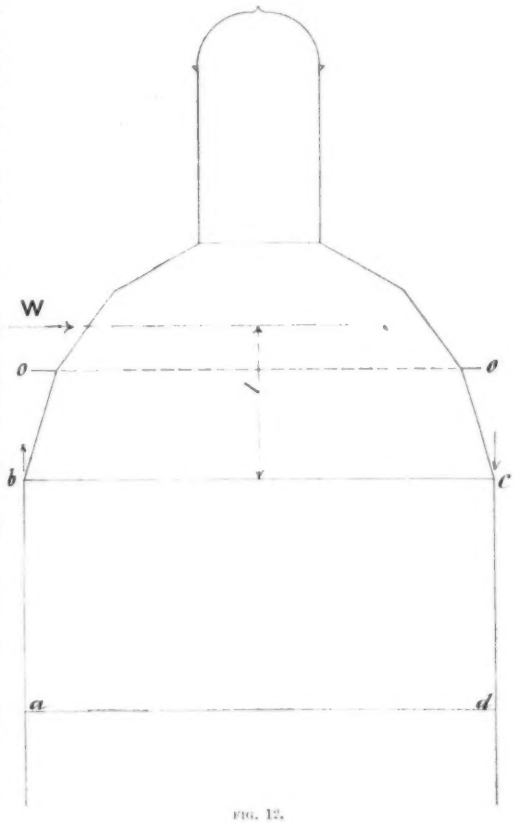


FIG. 12.

ing moment equal to W l, and a shearing force equal to W.

The bending moment produces an upward pressure at b, and a downward pressure at c, equal to $x = \dfrac{\mathrm{W}\,l}{b\,c}$.

21. If we are dealing with some section $o\,o'$, where the bars resisting these stresses are inclined at equal angles to the horizon in place of being upright, as in fig. 13; then let o, fig. 14, represent the point b, where there is acting an upward force (1) of $\dfrac{\mathrm{W}\,l}{b\,c}$; a horizontal force (2) of $\dfrac{\mathrm{W}}{2}$

(assuming that the shear W acts equally at b and c); the force (3) in the bar $a\,b$, and the force (4) in the bar $b\,c$.

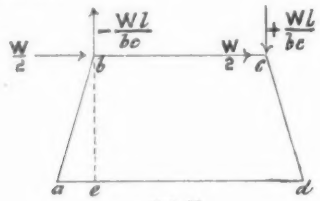


FIG. 13.

Set off to some scale $1.2 = \frac{W\,l}{b\,c}$; draw 2.3 parallel to $a\,b$; through 1 draw $3.4 = \frac{W}{2}$, and connect 4.3. Then 2.3 measured to that scale is the stress on the bar $b\,c$, and 4.1 the shear to be provided for at b, as the resistance to lateral action of the inclined bar $a\,b$ (= 3.1) provides

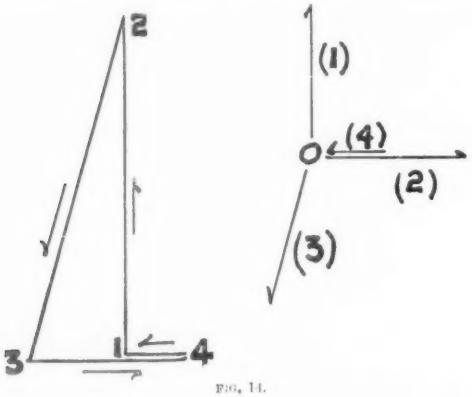


FIG. 14.

the remainder. The stresses at the point c are similar but opposite, with the exception of the shear 4.1, which is equal in magnitude but in the same direction as at b.

When, therefore, the bars supporting the section in question are not upright, but inclined as in the last figure, the shear to be taken by the bracing is reduced to $W - \left(\frac{a\,d - b\,e}{b\,e} \times \frac{W\,l}{b\,c}\right)$ being the total shear less the amount taken up by the slope of the legs.

22. Imagine next that fig. 12 represents the central vertical section of a square-framed figure, the plan of which is shown in fig. 15. The upward pressure at b and the downward pressure at c would still equal $\frac{W\,l}{b\,c}$ when the wind producing the bending moment $W\,l$ acted in the direction $b\,c$ (the direction of the diagonal); the bars at f and h would not be stressed by the bending, these bars being in the neutral axis of the frame.

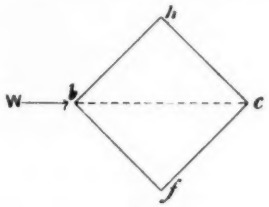


FIG. 15.

23. But if the frame be eight-sided in plan, as in fig. 16, the wind still acting in the direction of the diagonal, then in place of the resistance to bending being supplied by two points only, it will be supplied by six—three on each side of the neutral axis, there being still no stress due to bending on h and f (that is, assuming that the frame is so constructed as to act as one whole).

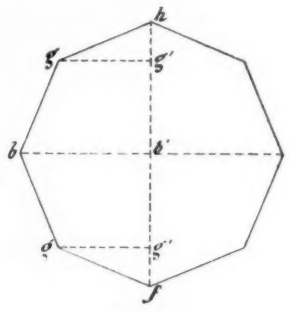


FIG. 16.

The stress upon the points b and g will vary according to the distances from the neutral axis $h\,f$. If, therefore, we call the pressure at b, say, x, we find the pressure at g by a simple proportion,

$$\text{as } b\,b' : g\,g' :: x : \text{ pressure at } g,$$

$$\text{that is } \frac{g\,g' \times x}{b\,b'} = \text{pressure at } g.$$

The moment of resistance at b, being the pressure multiplied by its distance from the neutral axis, is $x\,b\,b'$, and at g correspondingly is $x\frac{g\,g'}{b\,b'}\,g\,g'$. Adding the whole six we find the total moment of resistance equals

$$2\,x\,b\,b' + 4\,x\frac{g\,g'}{b\,b'}\,g\,g'.$$

But $2\,b\,b'$ equals the diameter $b\,c$; therefore the total moment of resistance equals

$$\text{diam. } x\left\{1 + 2\left(\frac{g\,g'}{b\,b'}\right)^2\right\}.$$

As in every regular octagon, the ratio $\frac{g\,g'}{b\,b'}$ is constant and equal to ·705, we may write the last equation

diam. x 1·99 = Moment of resistance.

As the bending moment (W l) is equal to the moment of resistance (diam. x 1·99), we find the maximum pressure x by dividing the former by diam. 1·99, or

$$x = \frac{\mathrm{W}\,l}{\text{diam. } 1{\cdot}99} = \frac{\mathrm{W}\,l}{b\,c\,1{\cdot}99}.$$

This, as before, is tension on the windward side and compression on the leeward side.

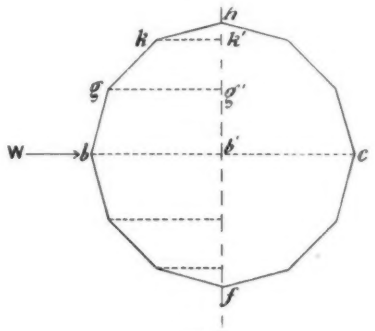


FIG. 17.

24. Suppose instead of an eight-sided we had a twelve-sided regular polygon. Then the total moment of resistance would be

$$2\,x\,b\,b' + 4\,x\,\frac{g\,g'}{b\,b'}\,g\,g' + 4\,x\,\frac{k\,k'}{b\,b'}\,k\,k'$$

$$= \text{diam. } x\left\{1 + 2\left(\frac{g\,g'}{b\,b'}\right)^2 + 2\left(\frac{k\,k'}{b\,b'}\right)^2\right.$$

$$= \text{diam. } x\,(1 + 1{\cdot}479 + {\cdot}5) = \text{diam. } x\,2{\cdot}979,$$

and for the maximum pressure at b and c (tension on windward, compression on leeward side)

$$\frac{\mathrm{W}\,l}{b\,c\,.\,2{\cdot}979}.$$

We would proceed similarly for any other regular-sided polygon, and find for an eighteen-sided figure the moment of resistance would be = diam. x . 4·526.

25. Besides the bending moment, which increases the pressure on one side and diminishes it on the other, by tending to overturn the structure, there is a shearing force tending to slide it bodily along in the direction of the wind.

Let fig. 18 show the plan of a square structure, and let W represent the direction of the wind. The shearing force tends to make it assume the position $a'\,b'\,c'\,d'$ shown by the strong lines. The resistance to this change is supplied by the bracing in the faces $a\,b$, $c\,d$, the shear in each being equal to $\frac{\mathrm{W}}{2}$. The faces $a\,c$, $b\,d$ do not supply any resistance to this force.

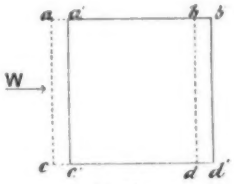


FIG. 18.

26. In fig. 19 we show an octagon and indicate the change in form under a shearing force by the strong lines. If we call the stress in the bracing $b\,c$ unity, the stress in the bracing $a\,b$ may be found by the "virtual velocity" of the force in $a\,b$. Let the points $a\,b\,c$ . . . . pass to the positions $a'\,b'\,c'$ . . . . ;

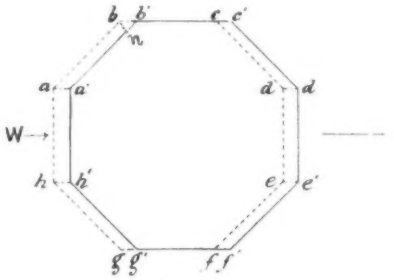


FIG. 19.

draw through b, $b\,n$ at right angles to $a\,b$; then the maximum displacement is $b\,b'$ = unity, and the virtual velocity of the force along $a\,b$ = $n\,b' = \frac{b\,b'}{\sqrt{2}} = \frac{1}{\sqrt{2}}$, as the frame is a regular octagon.

The shear is proportional to this, and the total stress in the bracing resisting shear $= 1 + 1 + 4\left(\frac{1}{\sqrt{2}}\right) = 4{\cdot}8$, when the stress on $b\,c$ is considered unity.

If we had a twelve-sided figure, we should find that the total shear would be 7·2 times, and for an eighteen-sided figure 13·3 times the shear in one of the parallel sides.

27. To find the maximum stress which occurs on each of the faces $b\,c$, $f\,g$, we divide the total shear by the number thus:

$$\text{shear on } b\,c = \frac{\text{total shear}}{4{\cdot}8} = \frac{\mathrm{W}}{4{\cdot}8}.$$

This shear might be taken up by two diagonals as shown by the dotted lines in fig. 20, each capable of resisting tension and compression, and bearing half or $\frac{\mathrm{W}}{9{\cdot}6}$; if the

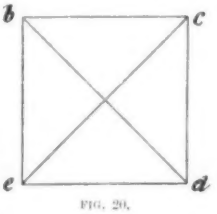


FIG. 20.

bracing bars $b\,d$, $e\,c$, resist tension or compression only, the shear in each would be as before $= \frac{W}{4{\cdot}8}$. To find the direct stress in the bracing bar $e\,c$, we should increase this in the proportion of $e\,c$ to $b\,c$.

28. It will be noted that motion or tendency to motion in the plane of the bracing produces stress according to the extent of that motion or tendency;

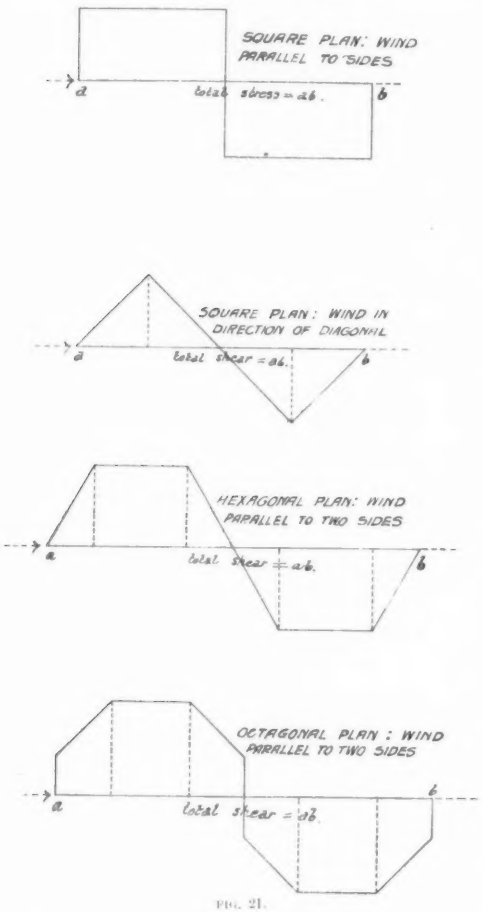


FIG. 21.

neither motion nor tendency to motion in the direction at right angles to that plane produces stress in the bracing. Accordingly, there is no shear in the faces $a\,h$, $d\,e$, fig. 19, and the motion $b\,b'$ of the face $a\,b$ is supposed to be compounded of two motions, one $b\,n$, in the direction at right angles to the plane of the bracing, producing, therefore, no stress in it; and one $n\,b'$, in the plane of the bracing, and producing a corresponding stress.

29. If we have any regular-sided polygon to deal with, we proceed in the same manner. The amount of shearing stress on any face may be found graphically as follows: for any plan, draw one half the plan on one side of a centre line $a\,b$, and repeat the other half on the other side of the centre line as in fig. 21, where shear diagrams are drawn for a square plan, lateral force parallel to one face; square plan, force in the direction of the diagonal; hexagonal plan, and octagonal plan, force parallel to two faces.

Then let the length $a\,b$ represent to some scale the shear W at the section considered; the projection of any side on this line, measured to the same scale, will give amount of shear taken up by that side. Note that the shear when acting in a direction parallel to the diagonal of a square, produces a less effect on the sides than when acting in a direction parallel to a side.

30. In any dome formed of ribs and rings, with wind bracing between, we may first find the stresses due to the weight of the structure itself by the graphical method in the preceding section, and write these against the corresponding pieces in the drawing, or put them into tabular form. Next above every section find the total wind pressure and its centre of action, and thence deduce the maximum stresses produced in the ribs, adding the compressions and deducting the tensions, to and from those due to the weight of the structure. On the leeward side the pressure will be increased, and on the windward side diminished, but usually there will still be compression on the windward rib. Then find the maximum shear on any face at each section, which will be the total wind pressure above that section (reduced as before, if the section has inclined sides), divided by two in the case of a square, or 4·8 in the case of an octagon, which maximum shear must be divided by the number of bracing bars acting in each panel, and increased by the ratio of the inclined length to the horizontal as already explained. We shall then have all the stresses due to wind pressure and dead load, and can proportion the pieces accordingly.

31. It is easy to find, by a direct graphical process, the stresses arising from a wind blowing in a direction parallel to two of the sides of a square tower such as that in fig. 22. Let that structure be framed up, and the lines of action of the wind be as there shown; letter the spaces and form the stress diagram by drawing $a'\,b'$ parallel and equal to $a\,b$; $b'\,c'$ to $b\,c$, and so on. Commencing at the apex, we know the force $a'\,b'$; from the ends draw lines parallel to $b\,f$ and $f\,a$; these, measured to the same scale as the wind forces, will give the stresses in the corresponding bars. The diagram may be completed now in the usual way, taking each nucleus in the frame, and making a corresponding polygon in the stress diagram. But when we have to deal with polygonal plans, it is not possible to get so simple a

solution. The method now to be described is, perhaps, as simple and direct as we can attain. Let fig. 23 be a vertical section through the centre and two opposite angles of a framed spire of, say, eight sides, and let $a\,b$, $b\,c$, $c\,d$, and $d\,e$ be the

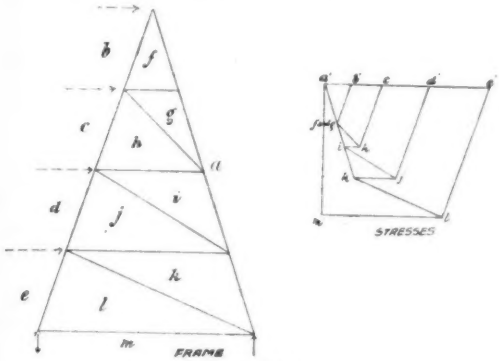


FIG. 22.

direction and points of application of the wind pressures at the various divisions. Find these amounts by multiplying the wind pressure per unit of suface by the area of the surface, the wind pressure, of course, varying with the inclination

diagram. Next produce the lines of action of the wind through these two figures.

In fig. 25 draw $c\,o$ at right angles to $a\,e$, and, choosing any point p in it as a pole, connect a, b, c, d, e with p by straight lines. Through o, where the highest line of action of the wind intersects $c\,o$, draw $o\,1$ parallel to $p\,d$; through 1, draw $1\,2$ parallel to $p\,e$; draw $2\,3$ parallel to $p\,b$, and $3\,4$ parallel to $p\,a$, producing these lines to cut $c\,o$ in $o'''\,o''\,o'$. This forms the bending moment diagram.

In fig. 24, through a draw $a\,f$; through b draw $g\,h$; through c draw $i\,j$; through d draw $k\,l$, and through e draw $e\,o$ at right angles to the force lines $a\,e$, cutting the lines of action of the wind, and so complete the shearing-force diagram.

From these we proceed to find the stresses, considering fig. 23 as a plane structure at first.

33. The point o''' in fig. 25 (obtained by producing $3\,4$ to intersection with $c\,o$) is on the line of action of the resultant of the wind pressures $a\,b$, $b\,c$, $c\,d$, $d\,e$; o'' (obtained by producing $2\,3$) is on the line of action of the resultant of $a\,b$, $c\,d$, $d\,e$, and similarly o' is on the line of action of the resultant of the pressures $c\,d$ and $d\,e$. Draw through these points horizontal lines to cut the corresponding points o''', o'', o' in fig. 23. To find the stresses in the bars $u\,v$, $p\,q$, and the shearing stress to be resisted in the frame $p\,q$, $u\,v$,

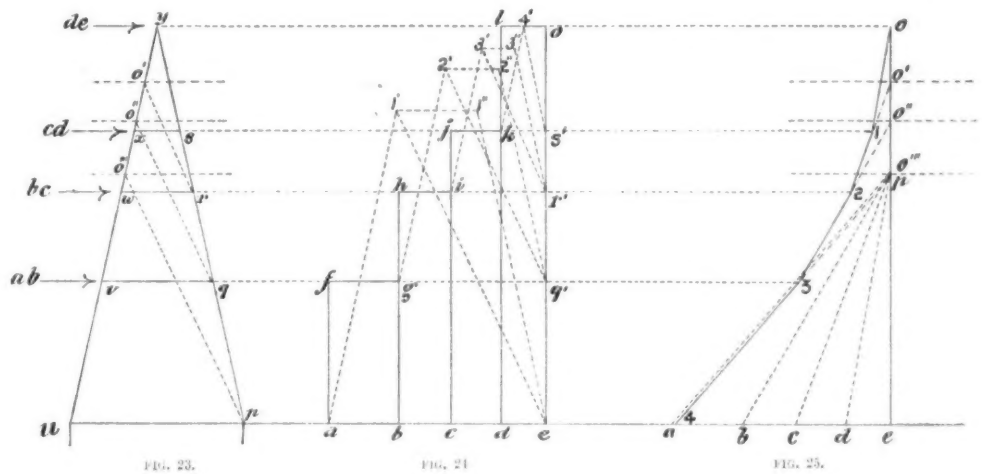


FIG. 23. FIG. 24 FIG. 25.

of the surface opposed to it. This would give the total wind pressure at each joint, were the surfaces at right angles to the wind; but as the surfaces are more or less "sloping" on plan, we must reduce it by multiplying by ·5 for a circular figure, and by ·56 for a polygon of eight sides.

32. On the base line produced, set off $a\,b$, $b\,c$, $c\,d$, $d\,e$ fig. 24 for the shearing force diagram, and the same again in fig. 25 for the bending moment

connect p with o''' (fig. 23), a point on the line of action of the wind pressures.

In fig. 24 the line $a\,e$ represents the total shearing stress between $v\,y$ and $p\,u$. Through a draw $a\,1'$ parallel to $u\,v$, and through e draw $e\,1'$ parallel to $p\,o'''$ in fig. 23. Draw through e the line $e\,1'$ parallel to $p\,q$, and $1'\,1''$ parallel to $a\,e$; $1'\,a$ is the tension in $u\,v$, $1'\,1''$ the shear to be provided for by the bracing, and $1''\,e$ is the pres-

sure in $p\,g$. This is on the supposition that fig. 23 is a plane structure.

Similarly we proceed at the section $v\,q$; $g\,q'$ in fig. 24 being the shearing force, by drawing $q\,o''$ (fig. 23); $q'\,2'$ parallel to it, and $g\,2', 2'\,2'', q'\,2''$ parallel to $v\,w$, $w\,r$, $q\,r$, respectively.

Then $2'\,2''$ is the shear in the bracing, and $g\,2'$, $q'\,2''$ the tension and thrust as before.

By the same process we arrive at the stresses and shears at the sections $w\,v$, $x\,s$.

Now the thrusts and tensions such as $g\,2'$ $q'\,2''$ would be the stresses upon single bars; but they are resisted by several bars. In this case we are dealing with an octagon, and the maximum stress on the windward bar is $-\frac{g\,2'}{1{\cdot}99}$, and $+\frac{q'\,2''}{1{\cdot}99}$ on the leeward bar, in accordance with the results previously found. Each of the stresses $a\,1'$ $g\,2'$, $i\,3'$, $k\,4'$, and $c\,1''$, $q'\,2''$, $r'\,3''$, $s'\,4'$, should therefore be divided by 1·99, and then added to or deducted from the stresses due to dead load, to find the maximum stress in the legs or angle rafters.

The shears $1'\,1''$, $2'\,2''$, &c., are similarly to be divided by (in this case where we are dealing with an octagon plan) 4·8 for the maximum shear on one face, and this result again is to be divided by the number of bracing bars (1 or 2) capable of resisting tension and compression, and increased by the ratio of its length to its horizontal extent.

34. The stresses due to wind and other irregular loading cannot be very accurately determined in the structures under discussion. It is true that if we assume that all the pieces of the frame have hinged joints—*i.e.* are free to turn at their ends—we can find the stresses with accuracy in the manner developed in Germany by Föppl, Hacker, and others, and by Professor R. H. Smith in England. Since writing the foregoing notes I have become acquainted with the works of these writers, the former by means of a work entitled *Calcul et Construction des Coupoles Métalliques Réticulaires*, par Pierre-Henri Brunelli, traduit de l'Italien par Désiré Mathieu, and the latter in his book called *Graphics*. But I cannot do better than quote from M. Mathieu's last chapter, written after developing in a very careful and beautiful manner the investigation of domes according to the manner of the authors mentioned above.

"Les calculs que nous avons décrits jusqu'ici permettent de résoudre exactement le problème de la détermination des tensions dans un système répondant rigoureusement à la définition que nous avons donnée en principe, c'est-à-dire dans lequel toutes les barres sont réunies entre elles par des articulations sphériques, et où tous les axes des barres concourent exactement au centre des nœuds, etc. Inutile de dire que de tels systèmes n'existent pas.

"On sait que, par suite de la rigidité des assemblages et de leur construction imparfaite, il se produit d'autres tensions, dites secondaires, et spécialement des moments fléchissants; il existe, dans la littérature technique, un grand nombre d'études et de mémoires concernant les systèmes plans; mais on ne peut en dire autant des systèmes dans l'espace, à cause de la difficulté du sujet. Pour ce qui nous concerne, nous ne connaissons, sur cette question, qu'un mémoire de M. Hacker, et quelques autres plus ou moins vagues et hypothétiques, dus aussi à M. Hacker ainsi qu'à MM. Föppl et Müller-Breslau.

"Les études de M. Hacker se rapportent à une coupole Schwedler symétrique et symétriquement chargée; dans ces conditions, il resulte des calculs qui ont été faits, que les tensions secondaires atteignent environ 30 per cent. des tensions principales. M. Hacker, se référant au mode de variation continue que l'on a, en général, en pratique, pour des charges non symétriques, croit pouvoir conclure aussi, dans ce cas, que les tensions secondaires ne dépassent pas la même proportion de 30 per cent. M. Föppl, d'une manière plus générale, pense que les systèmes à trois dimensions se comportent, sous ce rapport, d'une manière analogue aux systèmes plans; mais il renvoie tout jugement et toute étude ultérieure au jour où d'autres questions plus urgentes et plus importantes, sur ce sujet, actuellement à l'examen, auront été résolues.

"Nous n'avons donc encore sur cette question, prise dans sa forme la plus générale, aucune donnée positive, et les hypothèses et conséquences données jusqu'à ce jour paraissent assez vagues et peu certaines."

The stresses found by the method described in this paper appear to the author as near the truth as those found by the more rigid method, and certainly involve much less labour in determining them.